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Interagency Task Force on
Irrigation Efficiencies

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The potential for improving the efficiency of irrigation water use and management in the United States has been assessed by the task force and supporting technical work group. Although significant investments already are being made, the task force has determined that public and private investments of up to $5 billion should be made over the next three decades to implement needed water conservation measures. Investments of this magnitude can result in decreasing gross annual diversions by 15 to 20 million acre-feet and making 2 to 5 million acre-feet of water available for new uses. The task force recommends that the individual States take the leadership in coordinating and facilitating the site-specific studies and agreements that are prerequisite to implementation of the conservation measures. The various Federal programs would be called upon to assist State and local entities through technical assistance and financing as appropriate. The task force has pointed out a number of areas where additional Federal authority may be necessary to effectively assist the States achieve irrigation water conservation objectives.

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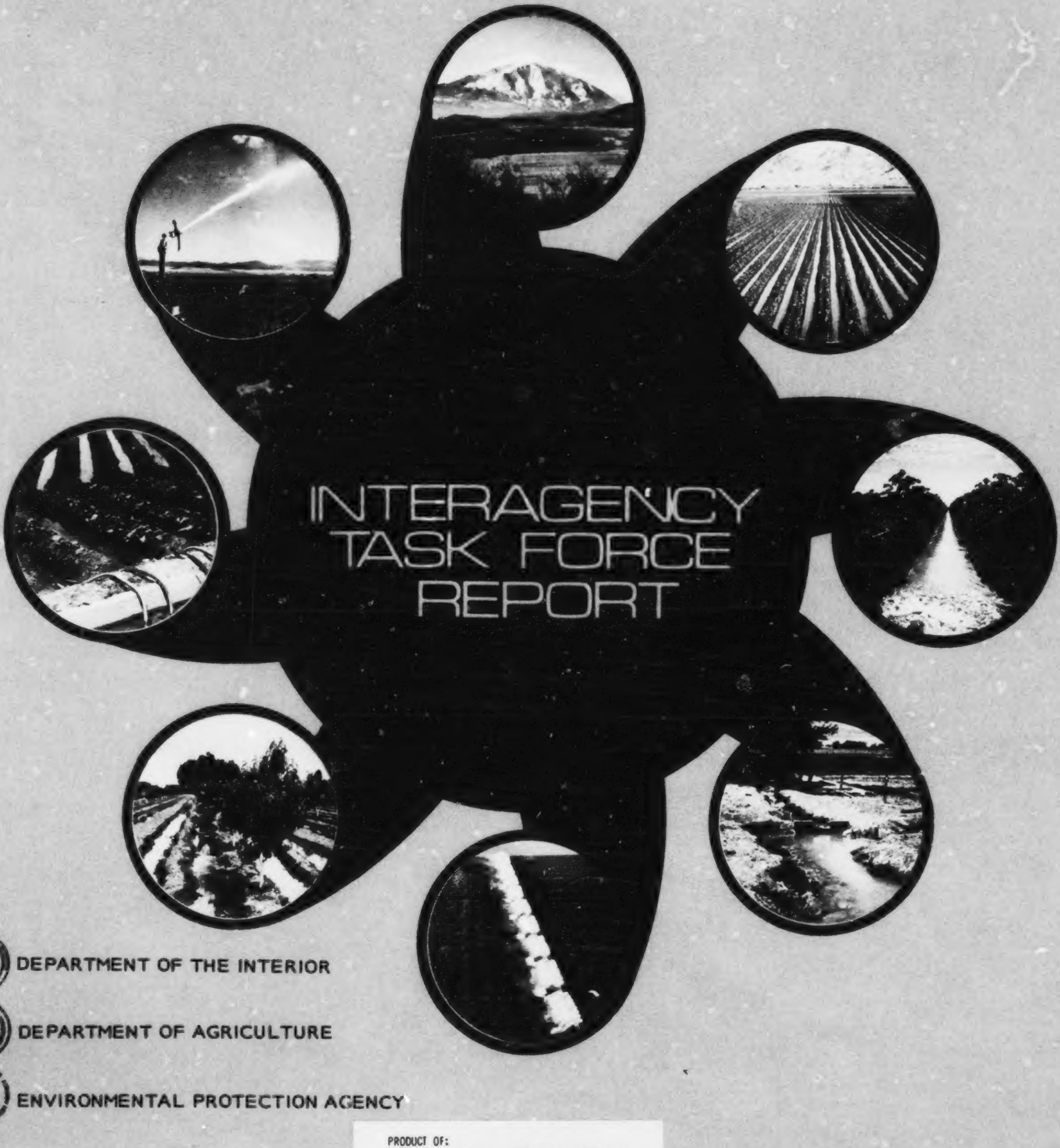

INTERAGENCY TASK FORCE REPORT

DEPARTMENT OF THE INTERIOR

DEPARTMENT OF AGRICULTURE

ENVIRONMENTAL PROTECTION AGENCY

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Irrigation Water Use and Management

An Interagency Task Force Report

U.S. Department of the Interior

U.S. Department of Agriculture

Environmental Protection Agency

June 1979

Foreword

The Interagency Task Force on Irrigation Efficiencies was established to examine the problem of inefficient irrigation in the United States and develop recommendations regarding appropriate Federal objectives, policies, agency roles, and action programs. Members of the task force include Eugene Hinds, chairman, representing the Department of the Interior; Joseph W. Haas, Department of Agriculture; and Joseph A. Krivak, Environmental Protection Agency. The task force appointed a Technical Work Group, with headquarters in Denver, to accomplish the required assembly, review, and analysis of data and the preparation of a report. Mr. Sheldon G. Boone, Director of the River Basins Division of the Soil Conservation Service, Department of Agriculture, was assigned full time to coordinate and expedite the efforts of the Technical Work Group and has been instrumental in completing the necessary studies and in editing this report.

Representatives of the Department of the Interior (Bureau of Reclamation, Bureau of Indian Affairs, Fish and Wildlife Service); the Department of Agriculture (Soil Conservation Service; Science and Education Administration; Economics, Statistics, and Cooperatives Service, Agricultural Stabilization and Conservation Service); the Environmental Protection Agency; and non-Federal entities have participated in the study. The States were represented by the Governor of Utah in his role as Chairman of the Subcommittee on Water Management, Natural Resources and Environmental Management Committee, of the National Governors' Association. Representatives of the State of Utah were active members on the Technical Work Group throughout the study. A number of the other 17 western States participated in work and review sessions.

A public involvement program was carried out by the Technical Work Group throughout the study. Public input was supplied through State representatives, interest groups, organizations, and individuals in the fields of agriculture and natural resources. Study information was mailed to these organizations and individuals for comment as it became available. A series of five public meetings was held in the western States in May 1978. Findings and tentative conclusions were discussed. Many excellent comments and suggestions were made and utilized in preparation of this report. The Technical Work Group appreciates the fine cooperation and assistance of these individuals and organizations.

This report reflects the President's concerns regarding water conservation as promulgated in his water policy reform message of June 6, 1978. In that message he states: "Managing our vital water resources depends on a balance of supply, demand, and wise use. Using water more efficiently is often cheaper and less damaging to the environment than developing additional supplies. While increases in supply will still be necessary, these reforms place emphasis on water conservation and make clear that this is now a national priority."

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Synopsis

The potential for improving the efficiency of irrigation water use and management in the United States has been assessed by the task force and supporting technical work group. Although significant investments already are being made by local interests, as well as by State and Federal Governments, the task force has determined that in addition to these ongoing programs, public and private investments of up to $5 billion should be made over the next three decades to implement needed water conservation measures.

It is expected that investments of this magnitude can result in decreasing gross annual diversions by 15 to 20 million acre-feet and making 2 to 5 million acre-feet of water available for new uses. The benefits from such improvements would be both qualitative and quantitative in nature, including increased national productivity, improved environmental quality, and a more stable social fabric for the agricultural community and the Nation as a whole. Environmental benefits from increasing instream flows would be significant.

Recognizing that local water using entities are the key to implementing water conservation measures and that other primary beneficiaries of water conservation are best represented at the local level, the task force recommends that the individual States take the leadership in coordinating and facilitating the site-specific studies and agreements that are prerequisite to implementation of the conservation measures.

The various Federal programs would be called upon to assist State and local entities through technical assistance and financing as appropriate. The task force has pointed out a number of areas where additional Federal authority may be necessary to effectively assist the States achieve irrigation water conservation objectives. The task force also suggests that involved Federal agencies adopt a formal mechanism for coordinating existing assistance programs. It assumes that the individual agency roles and the need for additional Federal authority will be addressed as a part of the implementation of the President's water policy, presently underway under the leadership of the Secretary of the Interior.

Introduction

In the last decade there has been a growing concern about irrigation efficiencies and water conservation. Concern has been expressed by many different interest groups, Government agencies, and the Congress. While the reasons for achieving improvements in water use efficiencies are varied, the consensus is that water is not being used wisely in some cases and that this should not be condoned in a country of increasing demand, finite resources, and environmental concerns. Because irrigated agriculture accounts for about 80 percent of all water consumed and nearly 50 percent of the total water diverted or withdrawn in the United States, major criticism has been directed to this use of water.

The primary purposes of this report are to (1) clarify the present use of water in irrigated agriculture, (2) address issues raised by the Comptroller General of the United States in his recent reports to the Congress on efficiency of onfarm and irrigation conveyance systems, (3) provide the Congress, the Administration, and the States with information on irrigation objectives, policies, and programs, and (4) unite interest groups, irrigators, and the general public in support of a clear-cut and effective national program of water conservation for irrigated agriculture.

Issues raised by the Comptroller General's reports to the Congress, presented as recommendations for further action by Secretaries of the Interior and Agriculture and the Administrator of the Environmental Protection Agency, are:

1. Develop more complete data on the adverse effects attributable to inefficient irrigation practices.
2. Determine the causes for such practices and the extent that each contributes to the problem.
3. Determine what Federal actions should be taken to alleviate the inefficient practices and the Federal agency or agencies best structured to administer such a role.
4. Identify and make needed improvements in obtaining conveyance system water-loss data to ensure that management has reasonably accurate information.
5. Identify problems and reasons that irrigation districts having the potential to conserve or better manage water resources are not improving their conveyance facilities.
6. Devise and recommend programs to the Congress for obtaining desirable improvements when the potential benefits to the basin or Nation are sufficient, but present programs are not likely to result in such improvements.

While this report does not address each point specifically, it answers these and other questions that have been raised about the effective use of water in irrigated agriculture. It is intended to be consistent with President Carter's statement on water policy of June 6, 1978, which stresses State-Federal cooperation in implementing ". . . programs which emphasize water conservation and which are tailored to each State's needs, including assessment of water delivery system rehabilitation needs and development of programs to protect and manage ground water and instream flows."

Because this report is concerned with currently irrigated land, it does not address water supply even though some storage may be needed to achieve better water management. The report does include activities which (a) reduce the demand for water; (b) improve efficiency in use and reduce losses and wastes; and (c) improve land management practices to conserve water. Irrigation efficiency, as used in this report, is defined in the glossary.

To some people in the western States, water conservation has come to mean storing water in reservoirs during periods of excess runoff to be released and used when the natural runoff is inadequate for desired use. To others, water conservation means cutting down on the use for some purposes so it can be allocated to other "important" purposes. And to still others it may mean keeping the raindrop on the land where it falls to reduce soil erosion and to replenish soil moisture, ground water, and streamflow.

To appreciate the need for or the importance of water conservation, it is necessary to understand the nature of water as a natural resource. Water is unique in its occurrence, immune to destruction by man, and its total supply is regulated by the hydrologic cycle. Its local occurrence and quantity can be modified and controlled to some degree, and its quality can be degraded, reducing its beneficial uses. This resource, vital to all living matter, is available annually in a predictable range. These properties make water different from soils or forest vegetation which can be depleted and then renewed, although at a very slow rate. Water as a resource is also different from coal, petroleum, or deposits of basic metals and other minerals which can be depleted but are not renewable. Only in the case of depletion of deep ground-water aquifers, which are not easily rechargeable, can man "borrow on the future" in the use of this resource.

While this report will define and show estimates of onfarm and water conveyance efficiencies, it is important that a more comprehensive concept of efficiency consider the productivity of water as well as emphasize water quality.

Conclusions, Recommendations, and States' Views

This section presents the conclusions and recommendations which the Interagency Task Force on Irrigation Efficiencies believes are the salient findings of the report. They highlight the more important aspects of irrigation water use and management that are related to water supply, water quality, and their associated economic, environmental, and other social values.

Conclusions

It is concluded that there are opportunities for reducing (1) seepage from onfarm and off-farm ditch and conveyance systems, (2) onfarm irrigation return flows, and (3) incidental water uses.[1] These reductions make possible an increase in benefits from use of the existing water supply. Changes that can be made in present irrigation water use and management to meet water needs have to be determined by a site-by-site analysis. The implementation of those changes which are fully acceptable from an economic, environmental, and social standpoint often will require public financial assistance.

Some of the identified benefits from efficient water use and management that may serve society and justify public financial support include:

1. Increased water supply for present users or junior appropriators, particularly in water-short years, and to meet emerging needs;
2. Improved water quality; and
3. Improved instream flows between point of diversion and point of return to the stream system.

All water in a hydrologic unit, such as a river basin system, is now serving some purpose; however, shifts in use can be made. The implementation of an irrigation water conservation program can have major impacts upon the quality, quantity, and timing of the water supply available at the points of diversion within a hydrologic unit. A careful multidiscipline analysis of the socioeconomic, agricultural, environmental, engineering, and hydrological aspects of conservation measures is needed to optimize the social value of the many consumptive and nonconsumptive uses of the available water supply. Careful planning considering water's mobility in meeting simultaneous and sequential uses in a basin will ensure cost-effective programs.

A more detailed statement of conclusions follows.

Chapter 1 - Irrigation in the United States

- Irrigated agriculture currently accounts for over 25 percent of the value of all crops produced in the United States on only about 12 percent of the cropland. Its importance in meeting our food and fiber requirements is clearly established. In most areas of the West agricultural production is dependent on irrigation, especially production of high value crops. Throughout the country, irrigation is being used to reduce economic risk of seasonal or prolonged drought and to assure crop quality.
- Irrigated agriculture has been and continues to be a major economic enterprise in the West. Values from irrigated agriculture are woven throughout the economic and social structure of the western United States.
- Irrigation is the major consumer of water in the Nation. Some other water users, both

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[1] See glossary for definitions.

consumptive and nonconsumptive, have expressed concern about this amount of use and the need for conservation.

- Conditions under which irrigation is practiced differ between areas. Generalized comparison of the effectiveness of water use between areas should be made cautiously, with full knowledge of the limitations.
- Generally, where water depletions exceed 70 percent of the historic average annual supply, the streamflow conditions and instream flow values can be severely affected.
- In many irrigated areas, significant wetlands and other wildlife habitat have formed which could be adversely affected by increasing irrigation efficiencies.
- Irrigated agriculture can have a major impact on water quality in some areas.
- The general lack of knowledge of the importance of irrigation return flow for use downstream leads to a serious misunderstanding about the consequences of low irrigation efficiencies.

Chapter 2 - Water Laws and Institutional Aspects

- Limited administrative control of water use is practiced in the humid eastern States that have adopted the Riparian Doctrine. However, where more and more water is being developed for irrigation, States are adopting permit programs or changing to the Prior Appropriation Doctrine to establish accounting procedures for such water uses.
- Under the Prior Appropriation Doctrine, as adopted by the western States and a few eastern States, **beneficial use** is the basis, measure, and limit of the water right. The beneficial use concept is flexible enough for State administrative agencies to implement strict control of inefficient irrigation water uses, as well as adjust to changing needs.
- Gradual changes are occurring in western water laws. For example, beneficial use in several States now includes water for such instream uses as fisheries, wildlife, recreation, and maintenance of water quality.
- Many institutions or organizations established under western State statutes for water resources development and use are very limited in their authority. Changes in statutes often are needed to bring about irrigation water conservation. In some situations, it may be desirable to combine many of the "single-purpose" institutions or organizations into one "multiple-use" institution or organization to handle irrigation, flood control, ground-water management, and other water uses.
- Many of the States presently do not have laws that control the use of ground water. Legislation may be needed in such States to achieve efficient use of the water supply.

Chapter 3 - Ongoing Programs Related to Irrigated Agriculture

- In addition to the funding available for construction of major Federal irrigation projects, about $175 million of Federal funds are expended annually to improve irrigation water use and management. These funds are available for planning, technical assistance, research, education, cost-sharing, and loans. Approximately $800 million was spent by the private sector in 1977 to improve individual water supply and distribution systems.
- While many Federal programs are applicable to irrigation water use and management problems, few of the approximately 40 programs evaluated have the conservation of water as their major objective.
- It was indicated that about one-third of the irrigation water use and management programs could be more effective if program policy changes and priority adjustments were made. One-half of all programs need additional funds and personnel.
- Seven western States have initiated programs for the purpose of improving irrigation water use and management. Experience in administering these programs shows that States can play a greater and more effective role in any new national thrust for water conservation.
- Better coordination among Federal programs and with State and local organizations, including environmental entities, is necessary if

national water conservation objectives are to be met.

Chapter 4 - Inefficiencies, Causes and Results

- Lack of off-farm and onfarm water measurement limits achievement of efficient and cost effective water use and management.
- Inefficient water use and management in some areas contributes to waterlogged lands and noncrop vegetative growth.
- Poor irrigation water management can cause degradation of water quality, excessive energy use for pumping, and instream flow reductions.
- Diversions from some streams have occurred to the point that instream aquatic communities have been impaired. This is a characteristic of some of the older irrigation systems. In some other areas, use of streams to convey stored irrigation water has resulted in creation of outstanding aquatic communities, including excellent sport fisheries.
- The major water losses from off-farm conveyance systems result from seepage through unlined canals and through cracks and breaks in lined canals, from operational spills as a result of poor system design or management, and from excessive vegetative growth in and adjacent to canals.
- The major water losses onfarm result from surface runoff, deep percolation of applied irrigation water, and seepage from unlined field ditches.
- Present day institutional and social factors that affect irrigation efficiencies include the interpretation and administration of water laws and court decrees; attitudes that land and water are private property to be used as desired; limited financial capabilities; substitution of water for irrigation labor and capital investment; conflicts between water use instream and wetland habitat; and shortage of technical assistance and education to water users.
- Efficient irrigation water use and management is difficult in the intermediate valleys because the problems encountered are complex.
- The disparity between patterns of seasonal water supply and crop needs sometimes results in excessive applications of irrigation water during peak flow periods to buffer the effects of late-season shortages.

Chapter 5 - Measures, Costs, and Impacts

- Irrigation water use and management systems can benefit from reservoir storage to provide adequate water supply during seasons of low streamflow.
- Many older, obsolete conveyance systems cannot be managed efficiently or be adapted to delivering water on demand.
- In many cases, water must be delivered on demand to achieve high efficiencies. This requires a complex and flexible storage and conveyance system with effective control facilities, pertinent operating policies, and wise management.
- Some canal systems are not well adapted to delivery on demand without substantial off-canal storage reservoirs. Pressurized distribution systems, while more adapted to demand water delivery, are more costly, may require more energy, and require more sophisticated technical and administrative management capability.
- Well-designed onfarm irrigation systems are needed to achieve a high degree of application efficiency. Systems must be geared to soil characteristics, topography, and cropping patterns.
- Efficient use of water, even with adequate systems, requires careful management practices. Means of determining crop water requirements during the growing season, along with soil water-holding capacities, are necessary in planning time, amount, and rate of water application.
- Coordination is needed between conveyance and onfarm systems designers and the irrigation water management personnel to assure that compatible design and water-scheduling standards are being used.
- The installation cost of the physical works to achieve state-of-the-art improvement in

conveyance and onfarm systems in the 17 western States is estimated to be $14.6 billion. This does not include mitigation costs. The gross diversions would be reduced an estimated 38.6 million acre-feet. Net depletions would be reduced by an estimated 3.3 million acre-feet and represent salvaged water that would be available for additional use. Return flows would be reduced by 35.3 million acre-feet. A corresponding increase in depletions of 4.3 million acre-feet would result from firming up water supplies in areas now suffering seasonal water shortages.

- Under current evaluation criteria, only a part of the program outlined above may be attainable. In addition to ongoing program levels, an expenditure of $5 billion over the next 30 years can be feasibly invested to implement water conservation measures. This would result in making 2 to 5 million acre-feet of water available for additional uses and reducing diversions by 15 to 20 million acre-feet annually.

- Water conservation and reuse do not increase the natural water supply of a hydrologic basin. Such practices generally permit increased beneficial use of the total water supply. In some cases, the use of the ground-water supply may be prolonged, but in other cases the life of ground-water aquifers may be decreased.

- Other implications of a water conservation program may be:
  — Salvaged water available for additional uses results from reductions in phreatophyte-hydrophyte consumption, evaporation, and irrecoverable ground-water percolation.
  — The water rights of junior appropriators may be affected. Changes in return flow patterns could adversely affect points and timing of diversion; therefore, additional storage may be required.
  — Additional storage may be needed to permit better management and timing of streamflows to satisfy downstream water rights, enhance instream flows, and meet other objectives.
  — Surface return flows would carry reduced loads of nutrients, chemicals, sediment, and pesticides. Less seepage and deep percolation may reduce leaching of salts and nutrients.
  — Concentrations of some pollutants in return flows may be higher.
  — Improving water management practices will result in greater production per unit of water used. Variable costs of crop production such as fertilizers, labor, and water may be reduced.
  — Installation of new systems and improved water management may result in the loss of wildlife habitat where phreatophytes, hydrophytes, and seeped areas are reduced or eliminated.

Chapter 6 - Special Problems in the Humid Area

- Irrigation is an essential practice in sandy coastal areas, in areas adjacent to the lower Mississippi River, and in dry regions in Hawaii and Puerto Rico. Elsewhere in the humid area, irrigation is important as a means to improve the yield and quality of crops and to reduce the risk of crop failure due to drought.

- With few exceptions, irrigation water sources and systems in the humid area are individually developed and financed.

- Due to expanding agricultural markets and loss of prime farmlands to urbanization, less productive land with more erodible and droughty soils is being cleared. This land often requires irrigation to be profitable for agriculture.

- As water use increases, water laws need to provide for equitable allocation of water and priorities of use.

- Increased irrigation will require development of new water supplies to meet the withdrawal demands. Surface runoff is sufficient in most of the humid area to meet the demands for irrigation as well as other uses.

- Municipal wastewater, after adequate treatment to assure public health and safety, could be an irrigation water source and result in increased production and improved water quality.

- Special-purpose districts or other entities may need public financial and technical assistance to develop new surface water supplies.

- Future irrigation in the humid area will increase energy use, although some water conservation practices will reduce energy use.

- The development and use of new technology is needed to bring about improvement in irrigation water use and management. The most important assistance needed for adoption of new methods is in research, education, farm demonstrations, and technical assistance.

Chapter 7 — Approaches to Implementing Water Conservation Programs in Irrigated Agriculture

- The State Government appears to be the appropriate level to provide leadership for an aggressive and effective national program of water conservation.
- Because of the diversity that exists in irrigation and the high cost of implementing a complete and comprehensive program, priorities should be set on Federal, State, and local actions.
- The appropriate consideration of water quality, instream flow values, and groundwater resources in water conservation programs requires a basin-wide evaluation and analysis.
- Increased efforts by State water rights administering officials and court actions to include additional efficiency considerations in beneficial use determinations are needed to influence water users to practice water conservation.
- High onfarm or conveyance efficiency should be a planning or design objective only when that is the best way to optimize the overall use of water in a basin. Effective use of return flows and accumulating ground water may result in better use of the total water supply with less expenditure of other resources.
- Additional research in the breeding and development of crop varieties, determining crop water requirements, developing new equipment for irrigation scheduling, predicting rainfall probabilities, and improving irrigation water application methods are some of the continuing needs for increasing the efficiency of irrigation water use.
- Adoption of water-pricing policies to achieve irrigation water conservation can be effective if properly applied. Such policies need to include base rates for minimum requirements and substantially higher rates for amounts which are wasteful.
- Onsite benefits are the current incentives for practicing efficient irrigation water use both on farms and by irrigation districts. In some cases these may be small compared with offsite economic, social, and environmental benefits. A national program to achieve a significantly high level of irrigation efficiency would require financial assistance or tax credit, technical assistance, and education.
- To meet national water conservation objectives, better coordination of Federal programs is needed at both the State and Federal levels.
- In addition to ongoing programs, investment of up to $5 billion for measures to improve irrigation efficiencies over the next three decades appears justified. The local/State/Federal sharing of this investment needs to be addressed as a part of implementing the President's water policy.

Recommendations

The Interagency Task Force on Irrigation Efficiencies proposes the following recommendations for consideration of and appropriate action by Federal agencies, the Congress, States, and local organizations. These recommendations were developed by the Technical Work Group, taking into account review and comment from a wide spectrum of agencies, organizations, and individuals. The Task Force believes they are consistent with the President's water policy statement of June 6, 1978. Adoption of these recommendations would result in the implementation of a policy to emphasize the conservation of water used in irrigated agriculture and provide improved protection and management of water and related land resources. The Interagency Task Force recommends that:

1. Major public investments to improve existing irrigation systems be made after a comprehensive, interdisciplinary analysis has shown that better utilization of the water is needed, feasible, and consistent with State water plans and water rights procedures. This analysis should include assessment of

offsite benefits such as maintenance or enhancement of streamflows, water quality, and ground water.

2. The governor of each State in which irrigated agriculture is a major water user initiate and maintain a cooperative program through Federal, State, and local agencies and the private sector to bring about improvement in irrigation water use and management and to achieve water conservation (Cooperative Water Conservation Program — see chapter 7). Legislation should be introduced to provide for Federal grants to the States as needed specifically for this purpose.

3. The Nation invest up to $5 billion in addition to current efforts for measures to improve irrigation water use and management over the next three decades. Insofar as the benefits from such programs accrue to local and regional entities, as well as the Nation as a whole, costs of such improvements should be borne equitably by local, State, and Federal interests.

4. Federal agencies which carry out programs of assistance in irrigation water use and management specify, as a part of their annual budget submission, water conservation objectives of the program as identified in the Cooperative Water Conservation Program and the amount of funds and manpower to be made available.

5. Federal or federally assisted water resources planning include assessment of the need for and impact of sound water conservation measures to be implemented as a part of any proposed program or plan. The analysis should be carried out in a comprehensive and interdisciplinary manner consistent with Federal planning procedures and include analysis of ground water and surface water quantity and quality relationships.

6. Water quantity and quality data collection programs, including monitoring programs, be better coordinated among all agencies. The Federal Government aid the State as appropriate in developing comprehensive and easily accessible records of water use, emphasizing water quantity and quality, irrigation efficiencies, and instream flow needs to facilitate the enforcement of statutes relating to efficient use of water and the forfeiture and abandonment of water rights.

7. National leadership be exerted in water conservation programs. To achieve better nationwide coordination of State-Federal programs associated with irrigation water management, the involved agencies enter into memoranda of understanding which specify the mechanisms for mutual coordination consistent with the Cooperative Water Conservation Program of each State.

8. When conservation measures result in a reduction of incidental water use to maintain vegetative wildlife habitat, a portion of the salvaged water be designated, within State laws, for development of managed fish and wildlife habitat.

9. States using the Doctrine of Prior Appropriation develop and maintain flexibility within the laws to modify the definition of beneficial use to meet public needs and promote irrigation water conservation. As irrigation or other water use increases in nonappropriation States, legal and institutional systems should be modified to provide for water allocation in an equitable and environmentally sound manner.

10. State water agencies, together with the universities and extension service, take the lead in developing demonstration and educational programs to raise public awareness of the positive and negative effects of irrigation water use and to show the feasibility of implementing improved measures, including new technology.

11. The Federal Government increase research and technical assistance to achieve national water conservation objectives. Such efforts must be consistent and aligned with the Cooperative Water Conservation Program of each State.

12. Federal or State cost-sharing programs be considered along with all other incentives, such as tax rebates and interest-free loans, which are effective in meeting national water conservation objectives. Where substantial investments are needed to improve irrigation systems (off-farm and onfarm) or where offsite impacts are high compared with onsite benefits, substantial public financial assistance will be necessary. Conservation efforts should be concentrated in water-short areas where streamflow has been depleted, ground-water mining occurs, or surface and ground waters require conjunctive use.

13. All Federal, State, and local agencies and organizations which collect funds for the delivery of water implement a dollar rate structure which discourages the excessive use of irrigation water.

14. To assure protection of water quality and achievement of water quality goals with respect to irrigation, State-Federal efforts be made to identify and implement irrigation water management measures which improve water quality as well as provide for water conservation, and to determine the benefits with respect to water quality and environmental goals.

15. Projects authorized to provide Federal funds to support the development or rehabilitation of irrigation facilities contain arrangements for States and irrigation entities to make appropriate physical, administrative, or legislative provisions to ensure protection of water quality and instream flow values, and provide through public involvement a process to determine which stream reaches and instream values should be protected.

16. Contracts to obtain irrigation water from Federal or federally funded projects contain requirements for the establishment of effective water conservation measures.

States' Views

As the States' representative to the Interagency Task Force Technical Work Group, Scott M. Matheson, Governor of Utah, has supplied the following letter, dated February 28, 1979, which represents the States' views on this report:

"In September, 1977, Mr. Guy Martin contacted me as Chairman of the National Governors Association Subcommittee on Water Management to provide non-federal representatives on the Federal Interagency Technical Work Group on Irrigation Water Use and Management. Most of the 17 Western States have been represented at certain meetings, and Utah has participated fully in the total effort.

"The Technical Work Group in Denver released its final draft of the Irrigation Water Use and Management Report on December 20, 1978. We appreciate the cooperation of the Technical Work Group chairman in sending draft reports to interested states for their review and comment. We compliment the Technical Work Group for the comprehensive accumulation of general facts pertaining to irrigated agriculture and water management and they are to be commended for their diligent efforts.

"The states consider this report to represent a reasonably accurate overview of irrigated agriculture. The report spells out the diversity of problems and conditions which exist in the various generalized irrigated areas and indicates the potential for improving the efficient use and management of irrigation water supplies through the use of specific measures, practices and programs. We do not consider, however, that the proposed program and practices outlined in this report constitute an entire comprehensive program of water development and management.

"The recommendations of the work task force are only a component of a complete comprehensive program and will vary from place to place in degrees of importance and emphasis. Thus to attain the greatest success in water conservation, the efficiency program must be integrated with appropriate overall modifications into ongoing and future programs but must not be considered a complete substitute for the present ongoing programs. This is especially true in the use of storage reservoirs in the West.

"Water conservation does not provide any additional long-term water supply sources in the limited water resources areas of the western United States. It only delays the inevitable construction of additional storage facilities and allows the cost of such facilities to increase dramatically. Conservation practices which result in only marginal amounts of additional water may be less desirable than first conceived. The states request that structural measures to augment water supplies be given appropriate consideration whenever conservation measures are proposed.

"We fully support the report recommendation that the governor of each state in which irrigated agriculture is a major water user should initiate and maintain a cooperative program with federal, state, and local agencies, and the private sector to bring about improvements in irrigation water use and management. We feel the Cooperative Water Conservation Program coordinated by the states should always be a voluntary program with some economic incentives made available to the irrigators.

"The states are concerned that the report gives a false sense of potential "water saving" when it states a water reduction in gross diversions of 38.6 million acre-feet and a net depletion reduction of 3.3 million acre-feet (referred to as salvage water) in the 17 Western states. The report does not elaborate on the cost of developing the salvaged water at $14.6 billion to provide for certain structural and non-structural water conservation measures. In seasonally over-appropriated streams, which is the case in most irrigation states, the reduction in gross diversions will only provide additional instream flows between the diversion point and where the water returns to the stream. The return flow will not be available for the entire length of the river system. In most cases the salvaged water will be made available to the junior appropriator if the law of the states is observed. Often the junior water right is in the upper reaches of the river system which means less instream flows in the lower reaches. On river systems where the most senior appropriators are downstream, natural and/or return flows administered to reach the senior appropriator already benefit instream values.

"Where there is a reduction in gross diversions and salvaged water is made available in under-appropriated streams where there still exists a block of unallocated water, there is greater opportunity for instream flows to be made part of the law of the river; however, it cannot be expected that any state would give up any compact allocation of consumptive use to provide instream flows. The states have grave concern that the implied "savings of water" as a result of an expensive water conservation program is not as significant as these large figures imply when dispersed among the various water systems in all the irrigation states.

"The states are committed to and will hold firmly to the legal and moral concept of state control of water resources. It is the states' opinion that Recommendations Nos. 5, 14, and 15 are examples of an effort to secure some degree of federal dominance of the water resources of each state. Simply interpreted Recommendation No. 15 states that allocation of any federal assistance for "development or rehabilitation" will depend on how well the states satisfy the federal government relative to instream flows, groundwater, and water quality standards being considered. We are forced, therefore, to continue to reject the obvious purpose of federal dominance in a state prerogative as enunciated in Recommendation No. 15 and implied in Recommendations Nos. 5 and 14; and we would be a reluctant participant in any program if this federal attitude were to persist.

"As indicated above, the states have several reservations concerning this report and especially where the report inordinately emphasizes such values as instream flow and water quality standards. In a spirit of cooperation, we acknowledge that the report discusses the important possibilities of achieving efficient water conservation. The report as now written constitutes a basis upon which further discussion can be conducted. It is our understanding that the report may be modified in Washington, D.C., by the Federal Interagency Task Force. We would be very reluctant to support this report if any changes were made without state concurrence."

Chapter 1
Irrigation in the United States

The current status of irrigation in the United States reflects many years of development of land, water, and irrigation technology. As a result, the economies of many regions in the western United States are highly dependent on irrigated agriculture. The importance of irrigation is increasing in more humid parts of the Nation also, as farmers seek protection from the uncertainties of natural precipitation. The products of irrigated lands are essential to continued availability of abundant food supplies at reasonable prices in the United States as well as for export to other nations of the world.

This chapter is divided into three sections: Development and significance; land and water use for irrigation; and characterization of irrigation.

Development and Significance

History of Irrigation Development

Irrigation in the United States was practiced as early as 100 B.C. when the Hohokam Indians of the Southwest built canals to irrigate crops in the Salt River Valley of Arizona. The ancient systems at one time irrigated more than a quarter million acres, and the population supported by their irrigation has been estimated at a half million people. Crops of maize, beans, and squash were grown by the Hohokam and many other Indian tribes in the Southwest.

During the 16th and 17th centuries, the Spanish settlers and missionaries established modest irrigation works in the same general area. They introduced new irrigation techniques and practices which had been employed for centuries in their homelands. The Spanish taught the Indians their newest irrigation methods and introduced new irrigated crops such as grapes, fruits, vegetables, olives, wheat, and barley. The Spanish settlers had the first lined canals, using rock to construct stone troughs to conduct water from streams to orchards and vineyards.

The modern history of irrigation in the United States began with the settlement of the western regions in the 19th century. Early irrigation development was most rapid in the mid-1800's when settlers adopted and expanded the Spanish-American techniques. Large irrigated acreage was developed in the late 1800's and early 1900's in the western States. In more recent years, a significant amount of irrigation development has taken place in the humid eastern States.

In the West, level valley lands along streams were the first to be irrigated, using surface gravity methods. Private development of dams on small streams allowed water to be diverted into canals serving fertile lands near the streams. Finally, larger distribution and conveyance systems with control structures were developed by private organizations and Federal programs in order to reach more lands farther from the streams. The successful development of deep-well drilling equipment and power-driven centrifugal pumps gave increased access to supplies of surface and ground water for private irrigation development.

Today, large, efficient equipment is available to level and shape land surfaces, to shape and line canals and field ditches, and to install underground pipelines. Equipment to automate water control structures is available. The acreage on which gated pipe systems are used doubled between 1974 and 1977 (4 million acres to 8 million acres).[1] Where properly installed and utilized, surface methods of irrigation can be economical and utilize labor and water efficiently.

Large-scale sprinkler irrigation had its beginning in this country shortly after World War II when lightweight steel and aluminum piping became economically available. Sprinkler irrigation has spread from a few isolated areas to every State. In the late 1950's and early 1960's, self-propelled center-pivot sprinkler systems revolutionized the sprinkler irrigation industry. Until that time, sprinkler systems had to be moved by hand. Although several types of moving sprinklers are available today, the center-pivot sprinkler system is the most popular to reduce labor required to irrigate. Lands that were previously impractical to irrigate are being irrigated by sprinkler and drip systems. Sprinkler irrigated acreage has grown from several thousand acres in 1946 to 10 million acres in 1974.[2] Drip or trickle irrigation also has increased in recent years to a total of approximately 200,000 acres in 1977.[1]

Today's technology in irrigation (lined ditches, pipelines, automatic control structures and devices, moving sprinkler systems, trickle irrigation, and other modern techniques) provides the irrigator with many alternatives for conveying and applying irrigation water. Irrigation conveyance and application methods employed throughout the country vary from area to area and are related to economic feasibility. Generally, when the value of the crop grown is high, there is greater economic risk involved and the irrigation system needs to be more efficient.

Irrigated Acreage

Figures on irrigated acreage in the United States often vary from one report to another. The 1974 Census of Agriculture reported a total of 41.2 million irrigated acres in 50 States. The 1975 yearly irrigation survey issue of the **Irrigation Journal** showed 54 million acres, and the Second National Water Assessment, prepared by the Water Resources Council, showed 45.5 million acres in 1975. Differences occur because definitions of irrigated lands are not uniform among the different agencies.

The Census of Agriculture is taken every 5 years. The irrigated acreage shown includes only land irrigated during the year of the census, although additional acreage may have had irrigation systems. Census data are obtained by contact surveys of farmers and ranchers. The **Irrigation Journal** survey of irrigated acres is compiled from State and Federal agency estimates. Other surveys indicate that as many as 250,000 acres of irrigated lands are taken out of production each year for urban development. Often when irrigated acreages are estimated, this acreage loss is not taken into account, or the estimates may include lands developed for irrigation rather than lands actually irrigated during the year.

In this report, unless otherwise indicated, U.S. Census of Agriculture data will be used to show historical trends in irrigated acreage and the distribution between States, because a long period of record is available.

The Census of Agriculture indicates an increase of irrigated acreage from 18 million acres in 1939 to over 41 million acres in 1974, as shown in figure 1. Twenty States have 98 percent of the total irrigated land in the United States. Nearly 90 percent of the total irrigated acreage is located in the 17 western States. The eastern States of Florida, Arkansas, Louisiana, and Mississippi collectively account for over 8 percent of the irrigated area. (See table 1.)

Nebraska and Kansas have had substantial increases in irrigated land during the past 10 years — 1.75 million and 1 million acres, respectively. The water supply for this acreage has been developed primarily from ground water sources.

The rate of increase in total irrigated acreage began to slow between 1964 and 1969. Rapid expansion of irrigation in the 31 eastern States began about 1949 and continues to increase.

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[1] **Irrigation Survey Issue,** *Irrigation Journal,* **November/December 1974 and 1977.**

[2] **1974 U.S. Census of Agriculture.**

Table 1.—*Irrigation development — top 20 States — by irrigated acres and percent of harvested irrigated cropland to total harvested cropland.* (1974 U.S. Census of Agriculture)

State	Top 20 States, (by rank) 1974 acreage	Irrigated acres (1,000's) 1944	1954	1964	1974	Harvested irrigated cropland as percent of total harvested cropland
California	1	4,952	7,048	7,599	7,749	83
Texas	2	1,320	4,707	6,385	6,594	32
Nebraska	3	632	1,171	2,169	3,967	20
Colorado	4	2,699	2,263	2,690	2,874	42
Idaho	5	2,026	2,325	2,802	2,859	58
Kansas	6	96	332	1,004	2,010	8
Montana	7	1,555	1,891	1,893	1,759	18
Oregon	8	1,129	1,490	1,608	1,561	39
Florida	9	222	428	1,217	1,559[2]	46
Wyoming	10	1,354	1,263	1,571	1,460	66
Washington	11	520	778	1,150	1,309	23
Arizona	12	736	1,177	1,125	1,153	100
Utah	13	1,124	1,073	1,092	970	72
Arkansas	14	289	858	974	949[2]	15
New Mexico	15	535	650	813	867	65
Nevada	16	674	567	825	778	100
Louisiana	17	536	708	581	702[2]	21
Oklahoma	18	2	108	302	515	6
Mississippi	19	[1]	132	123	162[2]	3
South Dakota	20	53	90	130	152	1
All other States		85	493	1,003	1,294	
50 States, Total		20,539	29,552	37,056	41,243	

[1] Less than 500 acres.

[2] More up-to-date estimate of acreage used in Chapter 6.

The number of irrigated farms in the United States increased consistently over time through 1954. Since 1954, although irrigated acreage continued to increase, the number of farms has been decreasing. A large part of the decline in units can be attributed to the general trend throughout agriculture toward larger farms.

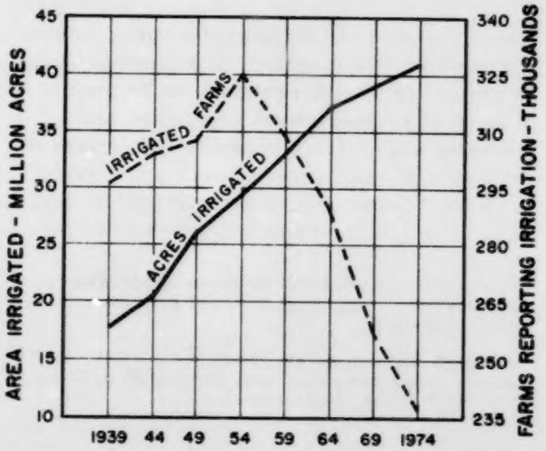

Figure 1.—Irrigated acres and number of irrigated farms, 1939 to 1974. (U.S. Census of Agriculture).

Federal Stimuli to Irrigation in the West

The Desert Land Act of 1877 and the Carey Act of 1894 were designed to stimulate private and State agency participation to put more western land into irrigated production. With the Reclamation Act of 1902, the Federal Government became even more involved in the irrigation development of the West. As a result of the establishment of the Bureau of Reclamation, many large-scale irrigation enterprises were undertaken which would have been beyond the financial capabilities of State governments and private enterprise alone. Today, Bureau of Reclamation projects deliver the total water supply to approximately

11 percent of the irrigated acreage in the 17 western States and a supplemental supply to about 9 percent.[3] In addition, the Department of Agriculture has provided technical and cost-sharing assistance and loans to owners and operators of irrigated land. The U.S. Army Corps of Engineers, Bureau of Indian Affairs, and Bureau of Land Management also have been involved in various phases of western irrigation development.

Irrigation Organizations

As water conveyance systems became more complex and expensive, different kinds of water supply and delivery institutions were organized to make continued development of water resources possible. These types of institutions vary greatly within and between States, depending on the kind of enabling legislation and the physical environment. The Census of Agriculture has grouped the institutions engaged in delivery of water to farms and ranches into seven basic types: Unincorporated mutuals, incorporated mutuals, irrigation and other types of districts, Bureau of Reclamation constructed and operated, Bureau of Indian Affairs, State and local government, and commercial and other organizations serving residences and businesses. The number of organizations, including all of the above, is shown on figure 2. The decrease in number of organizations and increase in acreage irrigated show a trend of smaller organizations being consolidated with larger organizations. Percent of irrigated acres served in each State by such organizations ranges from more than 75 percent in the Pacific Northwest and northern Rocky Mountains to less than 5 percent in the eastern United States.

Economic and Social Values of Irrigation

The development of irrigated agriculture has had considerable impact on the agricultural economy of the United States, particularly in the western States. In a recent study,[4] the average number of acres of irrigated cropland harvested for the 1971-73 period amounted to about 12 percent of the total acreage of all harvested cropland, but production had an estimated value of nearly $12 billion, 27 percent of the total value of all cropland production.

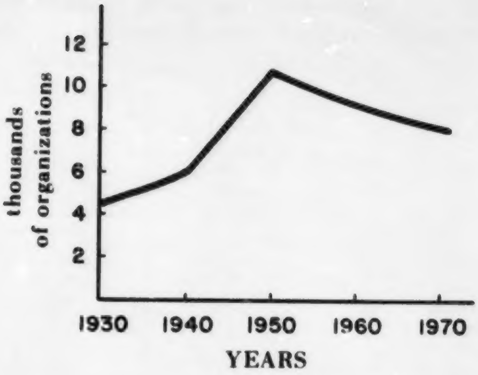

Figure 2.—Number of irrigation water organizations, 1930 to 1970, in the 17 western States. (U.S. Census of Agriculture.)

The regional importance of irrigated agriculture for crop production varies considerably from State to State. Nearly 90 percent of the total value of crops produced in California; over 80 percent in Utah, Idaho, New Mexico, and Wyoming; over 50 percent in Washington, Oregon, Colorado, Texas, and Florida; and nearly 50 percent in Nebraska were produced on irrigated land in the early 1970's. States such as Nevada and Arizona have little if any nonirrigated cropland.

The importance of irrigation also varies by crop. For example, it is estimated that approximately 90 percent of all citrus production; 75 percent or more of all potatoes, fresh vegetables, and processed vegetables; and nearly 100 percent of the almonds, sugar cane, and rice produced in the United States receive some irrigation. The value of irrigation to the farmer is higher per acre for fruits and vegetables than for most field crops. Such crops have high investment and production costs per acre which increase the economic risk of crop failure or yield reduction due to drought. Irrigation has reduced the risk of not getting adequate rainfall, allowing farmers to produce a plentiful supply of a high quality product at a lower cost to both producers and consumers.

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[3] Bureau of Reclamation 1976 Summary Report, Federal Reclamation Projects, Water and Land Resource Accomplishments.

[4] "Irrigated Agriculture, Past Trends, Present State and Problems of Future Expansion," unpublished draft by Dallas M. Lea, ESCS, USDA, Washington, D.C.

The total economic or social value of irrigation is more than just the increase in agricultural production due to irrigation. As agricultural production increases, the demand for fertilizer, machinery, pesticides, labor, and other commodities increases, generating additional economic growth which is estimated to be approximately equal to the growth in the value of agricultural production. Additional economic growth is generated in the agricultural processing and marketing industries.

The net value of output associated with irrigated lands under Bureau of Reclamation projects was nearly $5 billion in 1975. Crop production on those projects accounted for nearly $2.8 billion, livestock slightly over $0.1 billion, and food processing nearly $2 billion (table 2). Labor equivalent to 215,300 man-years was employed in producing the additional crop output resulting from reclamation projects.

Much of the West has developed and grown under an irrigated agriculture environment. Irrigation is a "way of life." Irrigation has made possible more intensive use of the land, increased the output in many sectors of the economy, improved the quality of food, and raised the standard of living. But at the same time, with irrigation have come some negative impacts such as reduced streamflows, declining ground-water tables, and impaired water quality. The positive and negative impacts need to be carefully studied and compared with present and future needs as changes in irrigated agriculture and other consumptive uses are made.

Table 2. — *Net increase in business activity, wages, and employment in the agriculture sector attributable to Reclamation projects, 1975.* (J. Gordon Milliken, Loretta C. Lohman and Reuben A. Zubrow, *Economic Impacts of Federal Reclamation Projects,* January 1977, prepared by the Denver Research Institute, University of Denver, for the Bureau of Reclamation, U.S. Department of the Interior.)

Type of output	Net value of output	Total wages and net farm income	Employment in man-years
	- - - million dollars - - -		thousands
Net crop production	2,786.9	1,643.7	215.3
Livestock	145.8	36.5	5.7
Food processors	1,958.0	1,078.0	121.6
Agriculture - Total	4,890.7	2,758.2	342.6

General Environmental Aspects of Irrigation

Irrigated agriculture has had a significant effect in modifying the natural environment, particularly in the western States. In much of the arid and semiarid West, water is the limiting resource and its availability takes on special significance, be it for agriculture, municipal and industrial supply, or various ecological functions.

As the major diverter and consumer of water, irrigated agriculture has had a profound impact on regional water budgets. These diversions and consumptive uses resulted, in some cases, in depleted streamflow conditions, ground-water overdrafts, degradation of water quality, and modification of terrestrial and aquatic habitats. In other cases, irrigation reservoirs have resulted in extended seasonal streamflow and improved water quality and aquatic habitat and have provided flood control and recreation.

In preparing the Second National Water Assessment,[5] depletion ratios (see glossary) were developed and analyzed to determine the relative instream flow conditions. Depletion ratios greater than 90 percent reflect seriously degraded instream flow conditions for fisheries, wildlife, and recreation[6] and can be equated with

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[5] The Nation's Water Resources: The Second National Water Assessment (1978), (Part IV, Water Supply and Water Quality Considerations and Appendix A-4, Streamflow Conditions), U.S. Water Resources Council, Washington, D.C.

[6] Bayha, Keith. 1978. "Instream Flow Methodologies for Regional/National Assessments: A State-of-the-Art Review." Instream Flow Information Paper No. 7. Fish and Wildlife Service Office of Biological Services 78/61, Fort Collins, Colo.

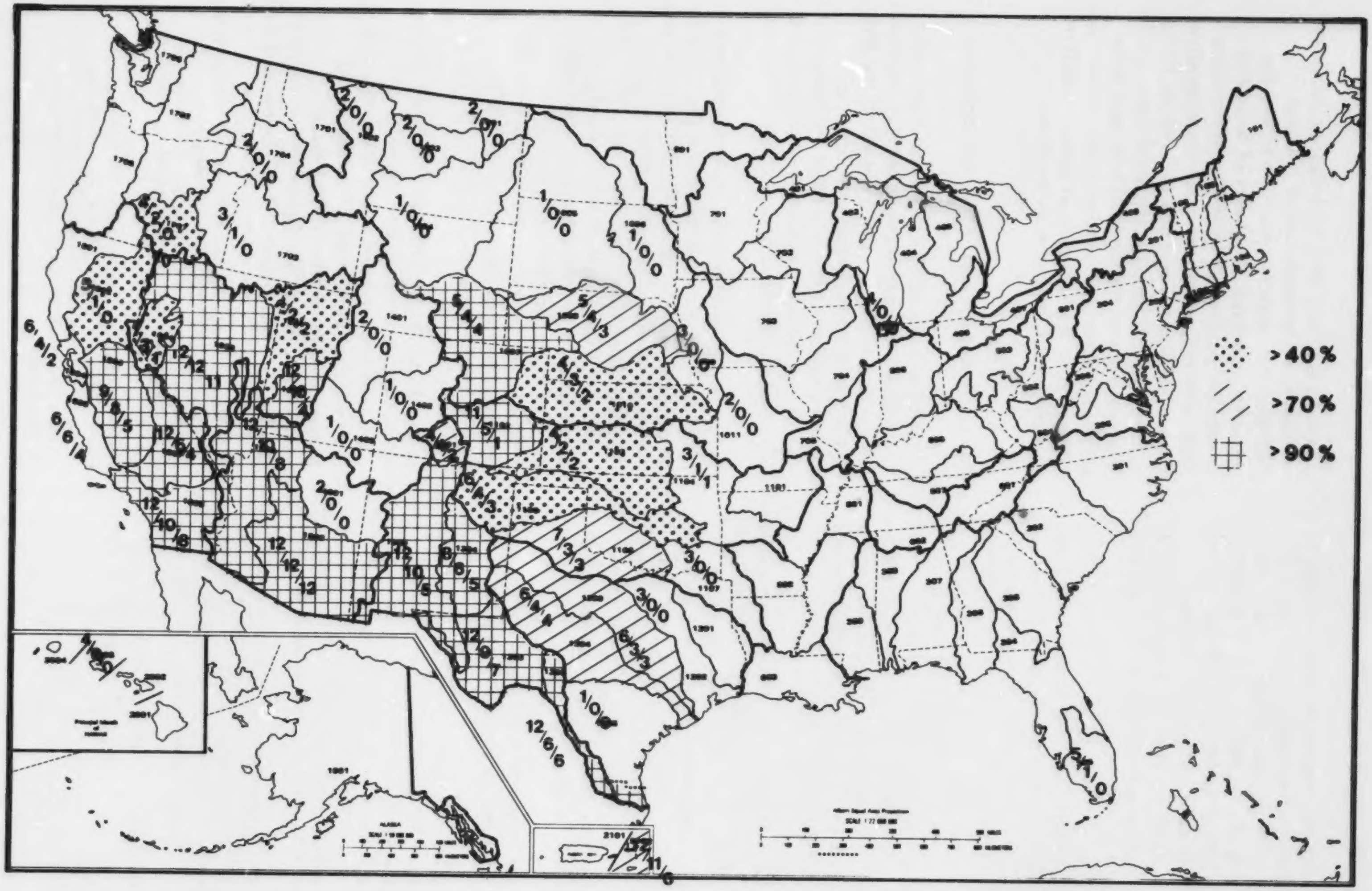

Figure 3.—Number of months per year when future streamflow depletion ratio is greater then 40/70/90 percent — average year. (Second National Water Assessment, Statistical Appendix.)

loss of desirable aquatic life and attendant benefits. Depletion ratios between 70 and 90 percent indicate instream flow conditions that are less than desired and are incapable of sustaining harvestable fish populations. Instream flow conditions in basins with depletion ratios from 40 to 70 percent are generally less than optimum, while depletion ratios less than 40 percent indicate generally healthy instream flow conditions. Computed depletion ratios reflect conditions at the outflow point(s) of a hydrologic unit, based on all upstream use and manipulations of supply. It is therefore possible for tributary streams to support viable fisheries even though the mainstream condition is severely depleted, or conversely, for severe instream flow problems to exist in some tributaries which are not reflected in these depletion ratios. Annual depletions tend to understate the real problem. Figure 3 indicates hydrologic units where the mean monthly depletions exceed the 40, 70, and 90 percent criteria. In areas with significant seasonal and annual storage, these ratios become less indicative.

In addition to its impact on water quantity, irrigated agriculture has a major effect on water quality. Irrigated agriculture can result in water quality degradation through a *concentrating process* (transpiration and evaporation of water results in increasing the concentration of constituents in the remaining water), and a *loading process* (contaminants added to the return flow from soils and substrata). Pollutants from irrigated agriculture are sediment, total dissolved solids ("salinity"), nutrients (phosphates and nitrates), and pesticides. Natural processes supply some of these pollutants. Separating irrigation impacts requires site-specific data and intensive studies.

Water use by irrigated agriculture has created significant environmental impacts in all areas. The magnitude of the impacts, both beneficial and adverse, varies with geographical and geopolitical location, as summarized below:

a. Seepage from both conveyance and onfarm distribution systems has created many diverse forms of fish and wildlife habitat. Habitat impacts carry over to riparian ecosystems and affect small game, waterfowl, and other residents of these systems.

b. Seepage from irrigation conveyance systems and inefficient water use has increased recharge of aquifers.

c. Diversions from some streams have impaired aquatic communities and migration of anadromous fish.

d. Return flows from irrigated areas may contain biocide residues, nutrients, and sediment, and may reduce the quality of many facets of the environment.

Irrigation and River Basin Hydrology

Basic principles of irrigation water diversions, application, and utilization need to be considered in relationship to efficient use of such water. Figure 4 shows the relationship between irrigation diversions, water use, and river basin hydrology.

To deliver a given amount of irrigation water to an irrigated crop, it is necessary to divert from the supply source (1)[7] amounts of water greater than that to be consumed by the crop. This diverted water may include return flow from other areas.

Diverted water may leave the irrigated area as crop evapotranspiration (11), seepage (5) from the conveyance system (canals and onfarm ditches), operational spills (6), deep percolation (3), tailwater runoff (4), evaporation (7), or as phreatophyte and hydrophyte consumption (10).

Seepage varies depending on the condition of the canals and onfarm ditches. Piped or lined conduits have lower seepage amounts than unlined channels. Most seepage and deep percolation returns to natural stream channels either directly via drains, or indirectly through ground-water aquifers (9). Return flows reaching natural stream channels again become available for instream use or downstream diversion (8). However, the return-flow water quality may be degraded. The recharge to

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[7] Numbers are located on sketch on figure 4.

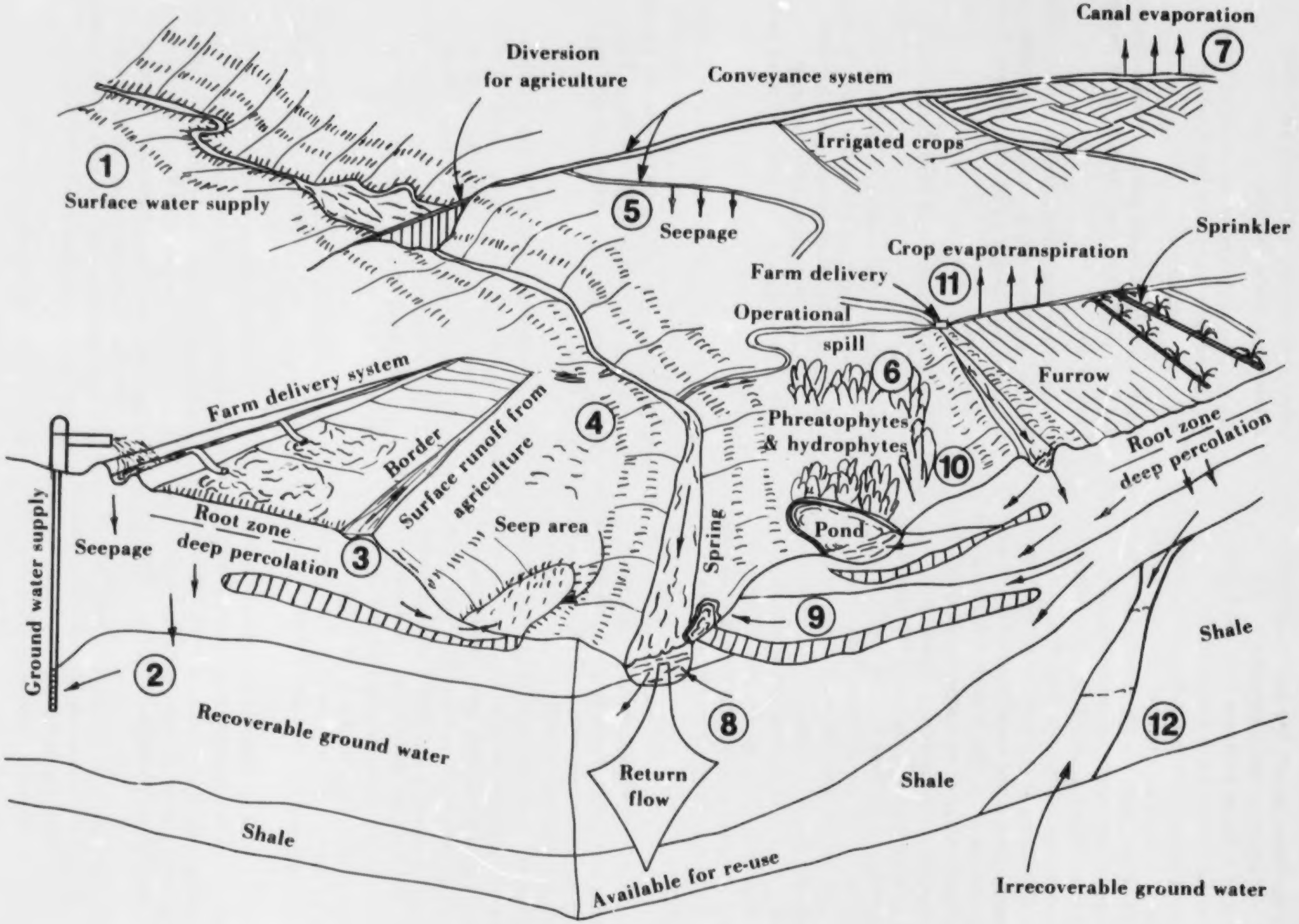
Canal evaporation
7
Diversion
for agriculture
Conveyance system
Irrigated crops
1
Surface water supply
5
Seepage
Sprinkler
Crop evapotranspiration
Farm delivery
11
Operational
spill
6
Furrow
Farm delivery system
Border
Surface runoff from
agriculture
4
Phreatophytes
& hydrophytes
10
Root zone
deep percolation
Seep area
Spring
Pond
Ground water supply
Seepage
Root zone
deep percolation
3
9
Shale
2
Recoverable ground water
8
12
Return
flow
Shale
Shale
Available for re-use
Irrecoverable ground water

Figure 4.—Schematic of irrigated river basin.

aquifers also serves to maintain ground-water supplies (2).

High early-season streamflows from snowmelt are diverted near the headwater. The entire diversion, irrigation, and return flow process may take from a few hours to a few months. The delays occur when a significant amount of flow returns through the ground-water system. These returns supplement the later season low flows that normally occur. The net effect is similar to reservoir storage in the basin. Thus, large increases in system efficiencies of "upstream" irrigation projects may require additional water storage to provide the same downstream water supplies later in the season.

Operational spills (6) result from a reduction in demand for water within the system after the water has been withdrawn from the supply source. These spills usually return to the natural stream channels via wasteways and become available for instream or downstream uses.

Phreatophyte or hydrophyte consumption (10) is noncrop vegetative transpiration of water that may occur adjacent to streams and channels, or in areas of shallow water tables. The existence of such vegetation often provides or enhances wildlife habitat.

A small quantity of deep percolation (3) (movement of water downward below root zone) is necessary to remove salts that would otherwise accumulate within the root zone, hampering and eventually prohibiting plant growth. This water is referred to as the leaching requirement and the quantity depends on soils, crops grown, climate, and water quality. Depending on geologic conditions, deep percolating water may slowly flow to deep aquifers or may enter stream systems through natural or manmade drainage systems. Deep percolation is often excessive as a result of poor irrigation management or nonuniform application inherent in many irrigation systems.

Filling the root zone on graded irrigation systems results in tailwater runoff (4) at the lower end of a farm field. The amount of runoff depends on soil conditions, irrigation system design, and water application methods. Some tailwater runoff may be unavoidable when graded surface irrigation systems are operated to achieve adequate infiltration and water application uniformity. Tailwater may evaporate, percolate, be consumed by phreatophytes, or reach stream channels as surface or ground-water return flow. Runoff may be collected onfarm and pumped back into the delivery system for reuse, or may be intercepted by other users as a supplemental or primary water source.

Diverted irrigation water that recharges a ground-water aquifer (2) through seepage or deep percolation adds to the water supply available to ground-water users. Some farms and small communities depend on these replenished supplies. In some cases aquifers are used to store and distribute excess surface supplies. "Irrecoverable ground water" (12) is ground water resulting from seepage or deep percolation that is not recoverable or usable.

Return flows (4, 6, 9) to natural stream channels resulting from tailwater runoff, drainage flows, operational spills, or ground-water discharge may provide all or a portion of a downstream user's water supply. Return flows from irrigation sources often increase the sustained flow in smaller streams to the extent that the stream can support limited fisheries not otherwise available.

Diverting less water for irrigation would generally not change the consumptive use on the irrigation project significantly. Additional water would be available for nonconsumptive instream uses between the points of diversion and return flow. The water would be available during the time the diversion would have been made, in the absence of reservoirs to store it.

Many irrigation projects have been developed, at least in part, in consideration of return flows and reuse. The streamflow in the lower reaches of most streams does not consist of new water, but of return flows of water previously diverted from the system in the upstream reaches. Thus, the system of storage and return flow provided by current irrigation practices affects other water-related development. Any irrigation improvements which alter this system need to be carefully considered.

Land and Water Use for Irrigation

Basic Principles of Farm Irrigation Systems

Irrigation systems are designed and operated to supply water to meet the crops' needs so that yields are not limited by water shortages. The crop root zone — that depth of soil (commonly 1.5 to 6 feet) in which roots are actively growing — provides a reservoir to store water from irrigation and precipitation until used by the crop. Water which infiltrates into this reservoir but exceeds its water capacity will percolate below reach of the roots and enter the groundwater system.

Water is used consumptively by irrigated crops through the processes of transpiration from leaf surfaces and evaporation from the soil. This consumptive use cannot be significantly changed by improving irrigation practices. For close growing crops, whose canopy essentially covers the field surface, the evapotranspiration is controlled by the availability of solar energy for evaporation and availability of water to be evaporated. Adequate water must be made available throughout the season to prevent reduced crop yields. Therefore, climatic conditions and type of crop generally govern water consumption.

Surface irrigation methods are used on approximately three-fourths of the irrigated land in the United States. The method is so named because the water flows over the surface of the irrigated field and infiltrates to fill the root zone. The irrigation stream should be large enough to cover the field quickly, to achieve high uniformity of water application, yet small enough to minimize soil erosion. Relatively large stream sizes, and corresponding stream diversions, are often required. For furrow irrigation, a rule of thumb for acceptable uniformity is that the stream should advance across the field in one-fourth of the total irrigation time. Thus, some surface runoff is occurring during three-fourths of the time. A smaller stream size might reduce runoff, but cause excessive deep percolation below the crop root zone at the upper end of the field, if the irrigation is continued long enough to adequately irrigate the lower end. Surface runoff may be relatively unchanged in quality and readily salvaged for reuse. Therefore, systems with runoff do not necessarily represent poor irrigation practice.

Use of sprinkler irrigation systems is increasing rapidly in most areas of the United States. Sprinklers — especially center-pivot, self-propelled sprinklers — are attractive to farmers because of their low labor requirements. Although most sprinkler systems are operated by pumps, there are a few that operate on gravity pressure. Application efficiency with properly managed sprinklers is often good if it is designed to apply water with high uniformity and at rates less than the soil intake rate, thus preventing runoff. Many people expect evaporation from sprinkler water droplets to be extremely high. However, under many conditions, total water consumption is not significantly greater for sprinkler irrigation than for surface methods. Wind drift and evaporation can reach about 25 percent of the water applied under conditions of high wind, high temperature, and low humidity.

Most sprinkler systems are operated at pressures ranging from 30 to 80 pounds per square inch. Pressurizing the water to this level requires energy consumption equivalent to lifting the water, by pumping, 70 to 185 feet.

Drip (trickle) irrigation systems have begun to be used on orchards, vineyards, vegetables, and sugar cane in the United States in the last 10 years. Drip systems use small plastic tubing, typically one-half inch in diameter, to transport water to the desired point of infiltration, where it is slowly applied to the soil through emitters or perforated tubing. The rate of application is usually 1 to 4 gallons per hour per emitter. Drip systems operate at lower pressures than sprinklers and can be designed to achieve high uniformity. Runoff and deep percolation can be almost entirely eliminated. Evaporation from soil is greatly reduced when drip irrigation is applied to widely spaced crops such as orchards or vineyards, because only a small percentage of the soil surface is wetted. Thus, the total irrigation requirement for such crops can be reduced below that occurring with surface or sprinkler irrigation. When drip systems are used on close growing crops, no equivalent reduction in consumptive use occurs. Drip systems are usually highly automated, making light, frequent (perhaps daily) irrigations practical. A potential exists for salt buildup in the soil over a period of time with drip systems.

Irrigation Water Withdrawals

As with irrigated acreage data, there are several sources describing water withdrawal and consumption for irrigation purposes. Figure 5 illustrates the relationship between agricultural and other water uses for the period 1955-75.

Data from the Second National Water Assessment indicate 177,800,000 acre-feet withdrawn for irrigation in 1975, 47 percent of withdrawals for all uses. Of the withdrawal, 96,800,000 acre-feet were consumed, accounting for 81 percent of all consumption. Thus, irrigated agriculture consumes a relatively high percentage of the water withdrawn. Other uses withdraw larger amounts of water than those withdrawn for irrigation purposes, but consume a much smaller portion of the water withdrawn.

Irrigation Efficiencies

A portion of the irrigation water diversion is consumed by irrigated crops through the process of evapotranspiration. That water not consumed by the crop is often referred to as water "lost" to the irrigator. Most lost water is returned to the system for reuse but some cannot be recovered, such as phreatophyte consumption, evaporation, and irrecoverable ground water.

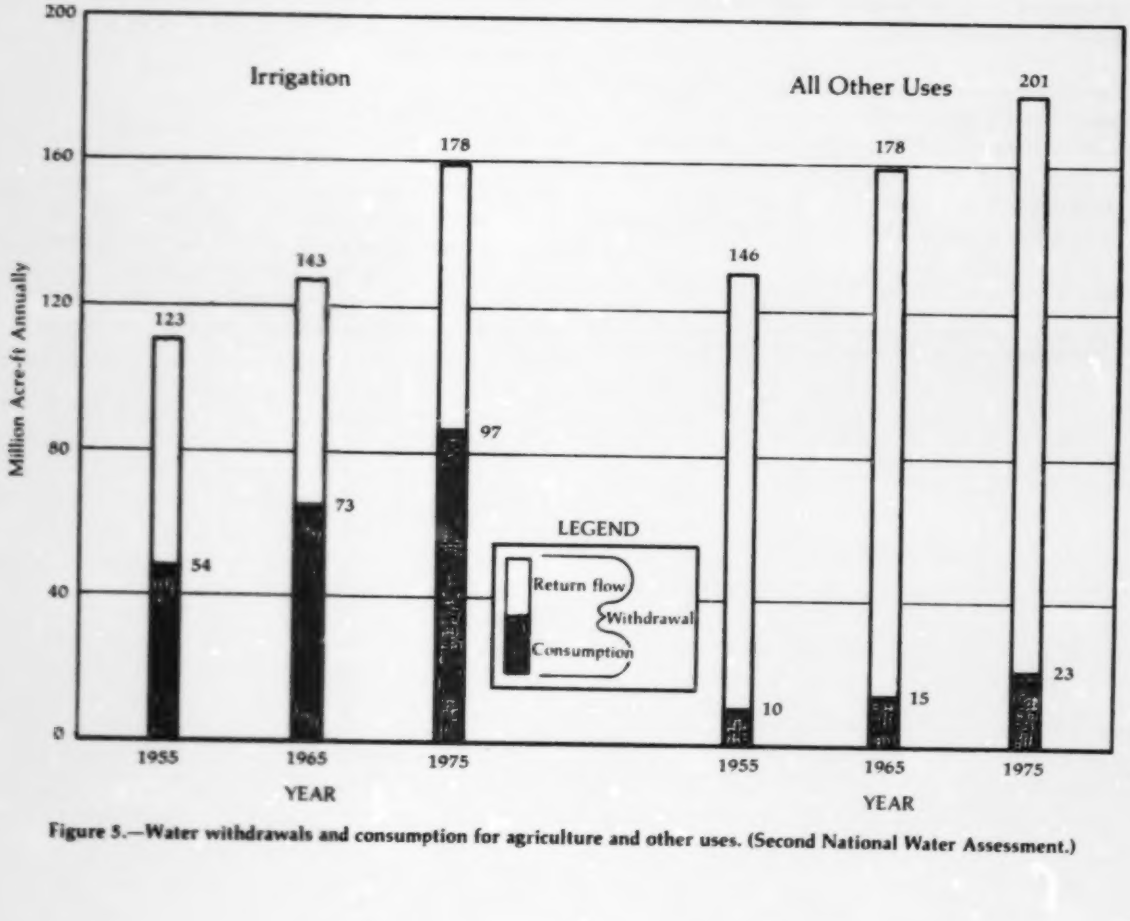

Figure 5.—Water withdrawals and consumption for agriculture and other uses. (Second National Water Assessment.)

Therefore, any report dealing with irrigation efficiencies must first define "efficiency" with a great deal of care. Many different and sometimes conflicting definitions have been published. It is frequently assumed that because an irrigation efficiency is low, much irrigation water is being wasted. This is not necessarily so. For irrigation efficiency definitions as used in this report, see the glossary.

In 1976, irrigation water requirements and efficiencies were evaluated for the entire United States by the Soil Conservation Service[a] as a part of the Second National Water Assessment. The report containing this information is referred to hereafter as the SCS report. Crop consumptive use, off-farm conveyance and onfarm efficiencies, gross diversions, incidental losses (uses), including irrecoverable ground water losses, and projected trends were determined for each of the 220 Water Resources Council subareas.

Figure 6 shows an irrigation water budget (total irrigation water diverted and its uses) for the United States in 1975, assuming a year with normal precipitation. Note that although crop consumptive use equals only 41 percent of diversions, another 46 percent returns to surface or ground waters for reuse, leaving only 13 percent irrecoverably lost.

A similar water budget for the 17 western States is shown on figure 7. Consumptive use, return flow, and irrecoverable losses represent about the same proportion of diversion as for the United States as a whole.

The average off-farm conveyance efficiency for the United States was estimated to be 78 percent, and the average onfarm efficiency 53 percent. The geographic distribution of these efficiencies is shown on figures 8 and 9. Efficiencies for each geographic area were estimated by different individuals, sometimes using differing procedures. As a result, values for different areas are not always directly comparable. Some experts feel that the listed efficiencies tend to be higher or lower than they actually are. However, the SCS report represents the one comprehensive study for all irrigation in the United States.

Current average off-farm conveyance and onfarm irrigation efficiencies of 78 and 53 percent do not mean that water currently diverted for irrigation can be saved and made available for other uses. Most of the water seeping from or running off the surface of any given irrigation system returns to stream channels or ground-water reservoirs where it is available for rediversion for irrigation or other use.

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[a] Soil Conservation Service, USDA, Crop Consumptive Irrigation Requirements and Irrigation Efficiency Coefficients for the United States, June 1976. (An appendix to the Nationwide Analysis, Second National Water Assessment.)

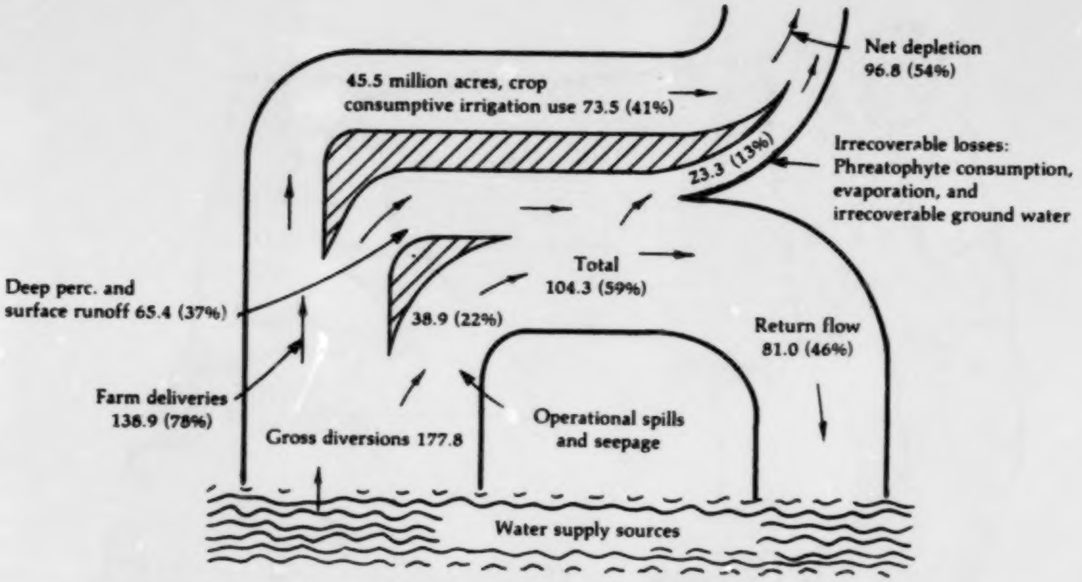
45.5 million acres, crop consumptive irrigation use 73.5 (41%)
Net depletion 96.8 (54%)
23.3 (13%)
Irrecoverable losses: Phreatophyte consumption, evaporation, and irrecoverable ground water
Total 104.3 (59%)
Deep perc. and surface runoff 65.4 (37%)
38.9 (22%)
Return flow 81.0 (46%)
Farm deliveries 138.9 (78%)
Gross diversions 177.8
Operational spills and seepage
Water supply sources

Figure 6.—Irrigation water budget for the United States and Caribbean for a year with normal water supplies, 1975 level of development (water quantities in millions of acre-feet). (Second National Water Assessment.)

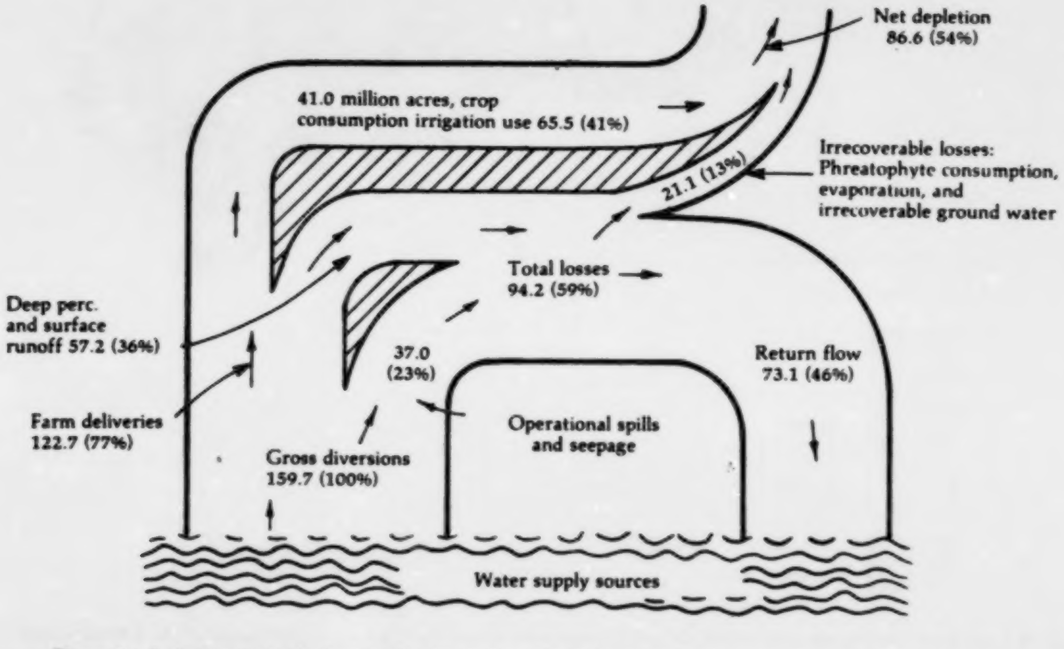
41.0 million acres, crop consumption irrigation use 65.5 (41%)
Net depletion 86.6 (54%)
21.1 (13%)
Irrecoverable losses: Phreatophyte consumption, evaporation, and irrecoverable ground water
Total losses 94.2 (59%)
Deep perc. and surface runoff 57.2 (36%)
37.0 (23%)
Return flow 73.1 (46%)
Farm deliveries 122.7 (77%)
Gross diversions 159.7 (100%)
Operational spills and seepage
Water supply sources

Figure 7.—Irrigation water budget for the 17 western States for a year with normal water supplies, 1975 level of development (water quantities in millions of acre-feet). (Second National Water Assessment.)

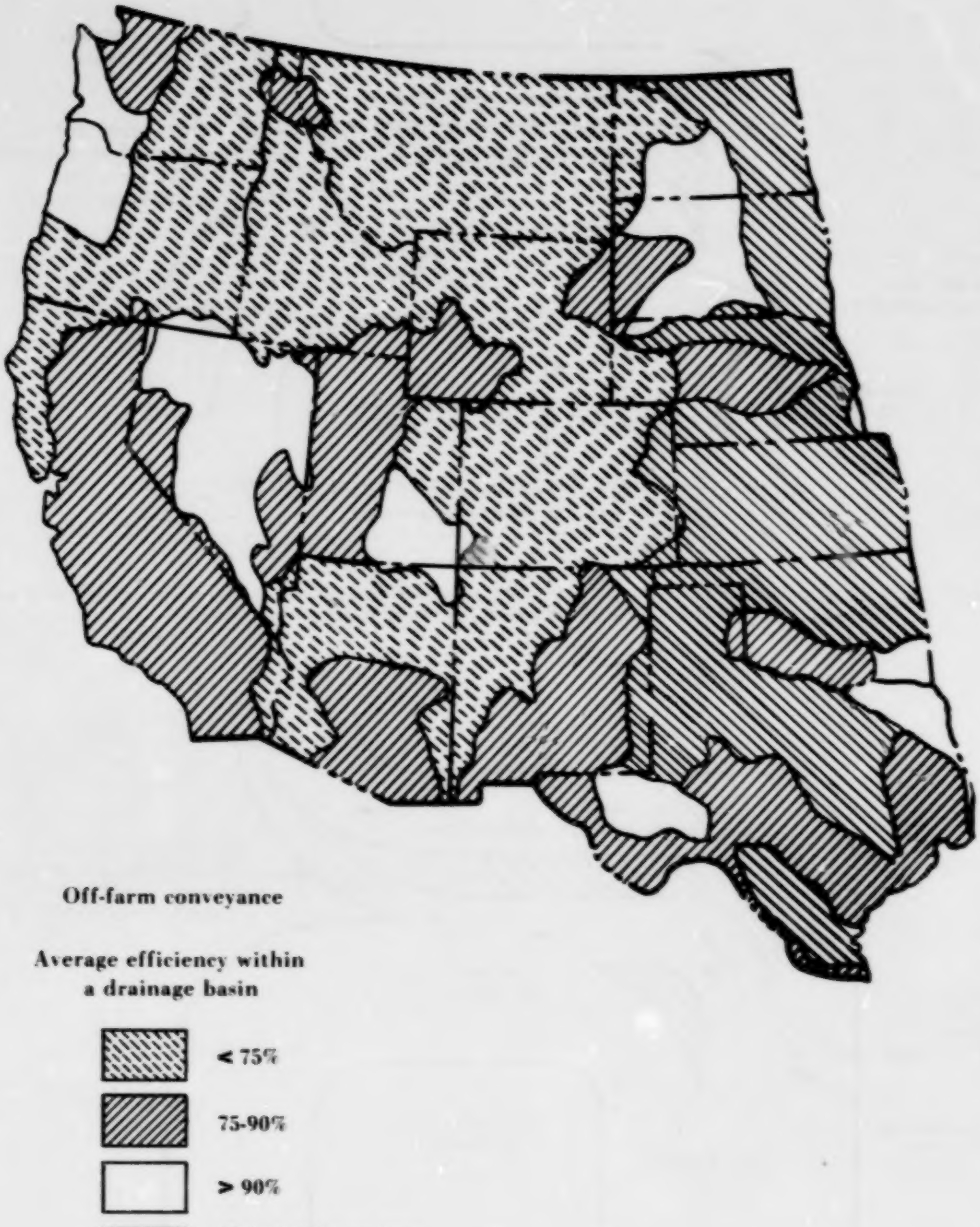
Off-farm conveyance
Average efficiency within a drainage basin
< 75%
75-90%
> 90%
Principally onfarm water supply

Figure 8.—Off-farm conveyance efficiencies. ("Crop Consumptive Irrigation Efficiency Coefficients for the United States," June 1976. Soil Conservation Service, USDA.) (An appendix to the Nationwide Analysis, Second National Water Assessment.)

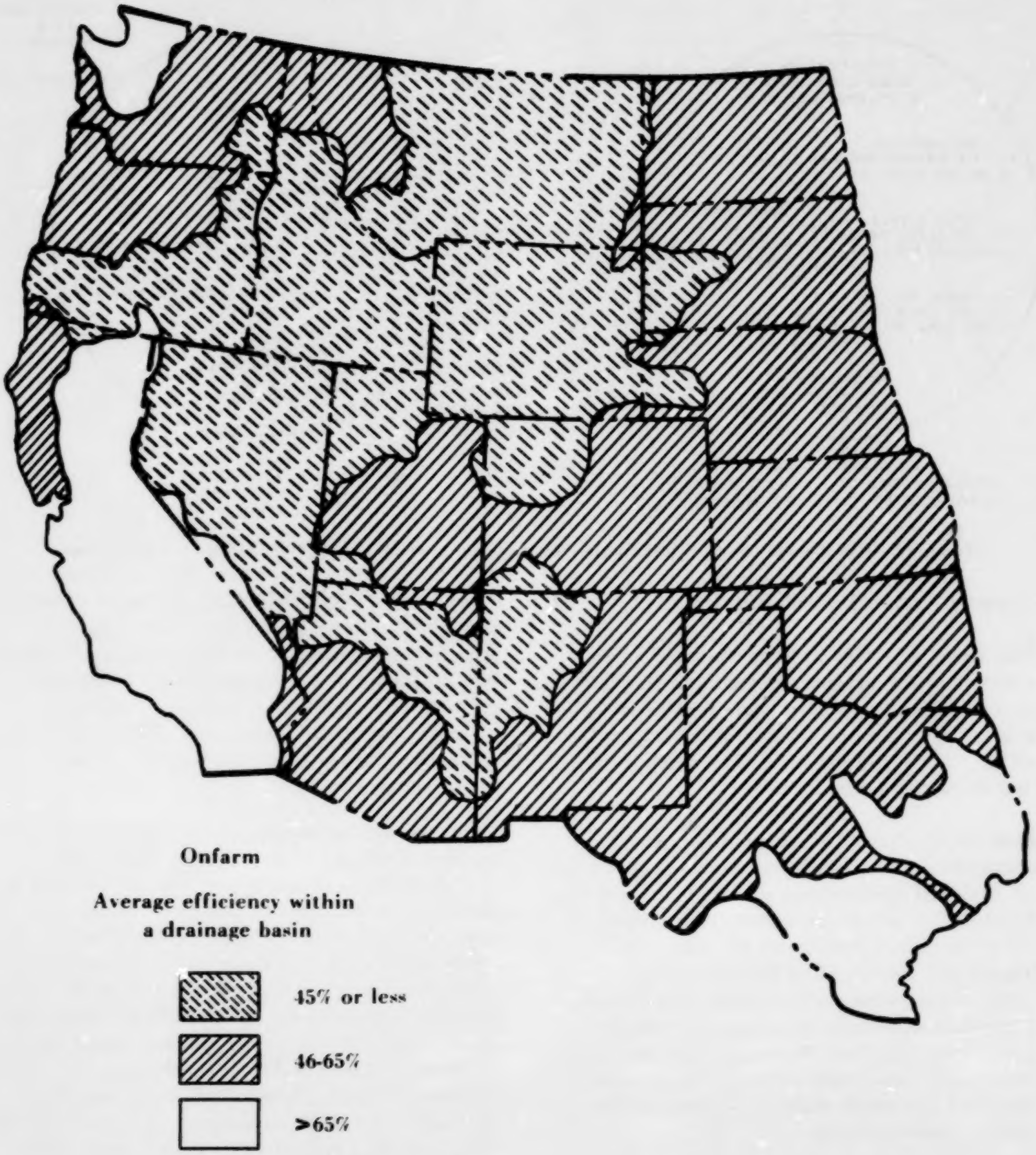
Onfarm
Average efficiency within a drainage basin
45% or less
46-65%
>65%

Figure 9.—Onfarm efficiencies. ("Crop Consumptive Irrigation Efficiency Coefficients for the United States," June 1976. Soil Conservation Service, USDA.) (An appendix to the Nationwide Analysis, Second National Water Assessment.)

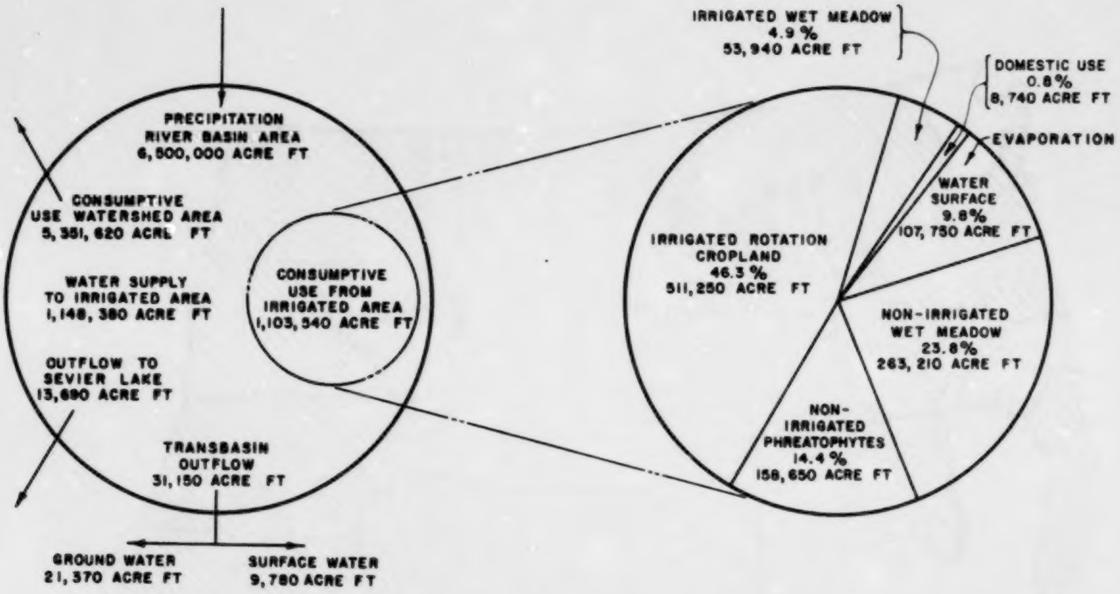
IRRIGATED WET MEADOW
4.9 %
53,940 ACRE FT
DOMESTIC USE
0.8%
8,740 ACRE FT
EVAPORATION
PRECIPITATION
RIVER BASIN AREA
6,500,000 ACRE FT
CONSUMPTIVE
USE WATERSHED AREA
5,351,620 ACRE FT
WATER SUPPLY
TO IRRIGATED AREA
1,148,380 ACRE FT
OUTFLOW TO
SEVIER LAKE
13,690 ACRE FT
TRANSBASIN
OUTFLOW
31,150 ACRE FT
GROUND WATER
21,370 ACRE FT
SURFACE WATER
9,780 ACRE FT
CONSUMPTIVE
USE FROM
IRRIGATED AREA
1,103,540 ACRE FT
IRRIGATED ROTATION
CROPLAND
46.3 %
511,250 ACRE FT
WATER
SURFACE
9.8%
107,750 ACRE FT
NON-IRRIGATED
WET MEADOW
23.8%
263,210 ACRE FT
NON-
IRRIGATED
PHREATOPHYTES
14.4 %
158,650 ACRE FT

Figure 10.—Water budget, Sevier River Basin, Utah, showing water consumed in the irrigation water budget.

Example: Sevier River Basin, Utah

The Sevier River in Utah can be used as an example of the magnitude of water savings to be expected by increasing irrigation efficiency. The average off-farm conveyance and onfarm efficiencies in the Sevier Basin are 67 percent and 45 percent, respectively.[9]

Even so, the Sevier is one of the most completely consumed rivers in the United States. Of the total precipitation of 6,500,000 acre-feet, 5,351,620 acre-feet are used consumptively on the nonirrigated portion of the watershed (figure 10). Nearly all of the remaining 1,148,380 acre-feet is consumed also. About 1.1 million acre-feet are delivered to the irrigated area. Outflows to Sevier Lake and other canals and rivers total only 45,000 acre-feet. Much of this saline outflow is available for further beneficial use.

Figure 10 also indicates the division of consumptive use within the irrigated area. Irrigated croplands and meadows account for 565,000 acre-feet. Thus, 51 percent of the available water supply is consumed beneficially by irrigated crops. Another one-fourth is consumed on nonirrigated wet meadows — a use that also benefits agriculture. The seeming inconsistency between efficiency values and basin utilization is a result of rediversion and reuse of "losses" from upstream irrigators.

Of the irrigation supply, one-fourth is consumed by phreatophytes or evaporation from reservoir surfaces — consumption that is not directly beneficial to agriculture. Since reservoirs are essential to provide for seasonal distribution of water supplies and to store water for use in dry years, the reservoir evaporation cannot be avoided. Theoretically, agriculture or other uses could benefit if part of the 158,650 acre-feet (14.4 percent of supply) currently used by phreatophytes could be saved. Improved irrigation systems and management will reduce return flow and phreatophyte use. Such action might, however, be detrimental to wildlife habitat as well as the aesthetic benefits that trees and shrubs provide in a desert environment. Furthermore, the costs and benefits of improving irrigation methods would need to be carefully analyzed to determine if they would be justified.

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[9] "Sevier River Basin, Utah," USDA-Economic Research Service, Forest Service and Soil Conservation Service, in cooperation with Department of Natural Resources, State of Utah.

Characterization of Irrigation

Irrigated Areas

As indicated earlier, irrigation practices and methods vary among areas of the country, and even within States, because of available water supply quantities and economic feasibilities. However, irrigated cropping programs are somewhat similar in areas with similar climatic conditions. Some of the primary considerations in development of irrigation are climate, amount of precipitation available, and the length of the freeze-free or growing season. Climatic conditions determine not only what crops can be grown on dryland in an area, but also which crops can be grown with irrigation and the amounts of water required to supplement precipitation. Average freeze-free season and the average annual precipitation for all areas of the United States are available in the "Climatic Atlas of the United States."[10]

Other factors affecting irrigation development are soil type, topography, quantity and quality of surface and ground waters available, and competitive uses for available water. These factors and others are identified in this chapter for six areas of the western United States, as shown on figure 11. Characteristics of the six areas are described below and are summarized in table 3.

Northwest Area

Mountain ranges rim this area of smooth to deeply dissected plains and plateaus. Irrigated lands lie at elevations from near sea level to about 6,500 feet. The area contains some mountain meadows, but generally consists of plateaus and plains with gently sloping valleys. All parts of the region have a pronounced dry season in summer, necessitating irrigation.

Irrigated soils in the mountain areas are shallow with rock outcrops and undulating and stony lands. Soils are formed from alluvial deposits in the valley floodplains.

Seventy to seventy-five percent of the irrigation water supplies in this area are from surface sources. About half of the lands are irrigated by surface irrigation methods and the other half by sprinkler methods. Approximately 75 percent of the water is delivered to the farms by irrigation organizations. Recharge of the ground-water aquifer in some irrigated agriculture areas occurs as a result of over-irrigation.

Anadromous salmon and steelhead, as well as other fish and wildlife, have been adversely affected by streamflow depletions and reservoir construction. Critical instream flow conditions are present in many of the areas due to multipurpose demands on the river systems. Several reaches in southern Idaho are often totally diverted for irrigation. Streamflows in the area are subject to a variety of water quality influences such as sediment, dissolved and suspended solids, nutrients, coliform bacteria, and temperatures. Irrigation return flows are a major contributor where adverse water quality conditions exist in southern Idaho, the Columbia Basin, and other irrigated areas. Waterfowl and upland game birds, as well as nongame species of wildlife, have benefited from habitat created by irrigated agriculture development. However, there has been loss of desert habitat areas that supported little or no wildlife.

Intermountain Area

Irrigated lands are sparsely scattered in the basins that lie between widely separated mountain ranges. They support a livestock economy which utilized the sparse desert shrub-grass vegetation on vast acreages of the public lands.

In the higher mountain elevations, the soils are shallow, undulating, and rocky. At the lower elevations, the irrigated soils are alluvial deposits increasing in depth and less rocky as the elevation decreases.

There is little summertime precipitation. Approximately 85 percent of the irrigation water supplies come from surface sources. Ground water may be saline, restricting its use for

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[10] U.S. Dept of Commerce, Environmental Sciences Administration, "Climatic Atlas of the United States," U.S. Government Printing Office, Washington, D.C., June 1968.

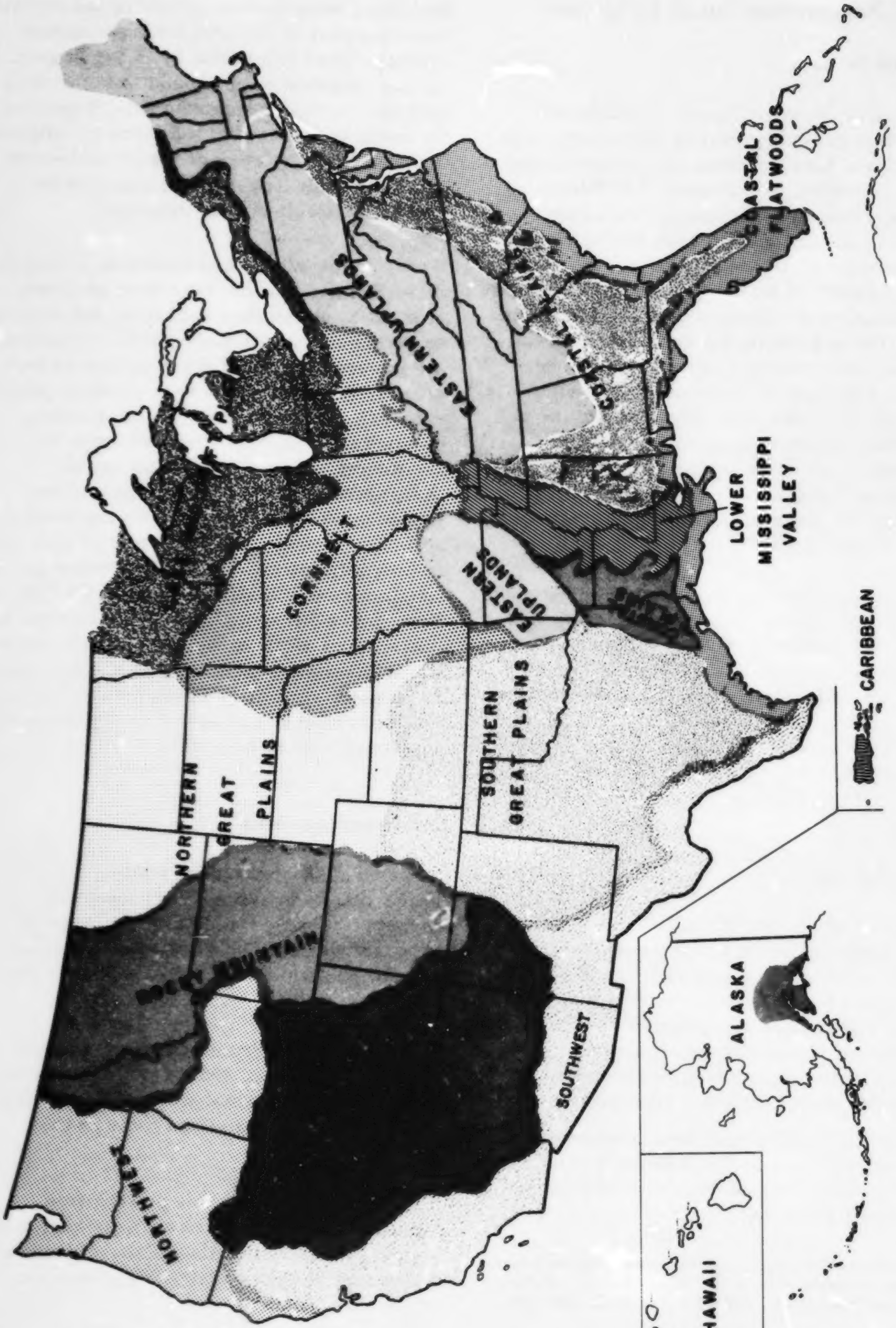

NORTHWEST
ROCKY MOUNTAIN
SOUTHWEST
NORTHERN GREAT PLAINS
SOUTHERN GREAT PLAINS
CORNBELT
EASTERN UPLANDS
EASTERN UPLANDS
COASTAL PLAINS
COASTAL FLATWOODS
LOWER MISSISSIPPI VALLEY
CARIBBEAN
ALASKA
HAWAII

Figure 11.—Irrigation characterization areas.

irrigation. Approximately 75 percent of the water is delivered to farms by irrigation organizations. Over 80 percent of the land in this area is irrigated by surface irrigation systems.

The streams support trout in the headwaters and warmwater species, a few of which are endangered, at the lower elevations. The impact of storage and salt loading is important to the fish and wildlife habitat. Riparian vegetation provides vital habitat to many wildlife species. The instream flow condition varies from healthy in the high country to severely depleted with poor quality in the valleys below irrigated lands. Throughout the Great Basin/Intermountain Desert area, irrigation return flows are responsible for much of the increased mineral load and impaired water quality in lower reaches of the river systems. Many wetland habitats (including several national wildlife refuges) are dependent on irrigation return flows. Improved irrigation efficiencies would help fish and wildlife if water were reallocated to instream uses and allowed to flow to the terminal lakes.

Southwest Area

This region of low mountains and broad valleys has a long, warm growing season conducive to highly intensive irrigated farming. The soils are generally deep and alluvial or wind-deposited. Many of the soils on the floodplains, low terraces, and dry desert areas are affected by salts and must be skillfully managed for satisfactory crop yields.

The rainfall occurs primarily from October to May. In desert portions of the area very little agriculture is possible without irrigation. Approximately half the irrigation water supply comes from surface sources and the other half from ground water. Between 60 and 70 percent of the water is delivered to farms by irrigation organizations. Surface water supplies, particularly in California, are delivered through a complex system of storage and transbasin diversions. Some 85 percent of the land in this area is irrigated by surface methods. The remainder is irrigated by sprinkler, trickle, or drip methods.

The instream conditions are characterized by severe depletion and high salinity and suspended solids in the lower valleys, to the point of being unsuitable for aquatic life in certain reaches. In some streams release of stored water during normally dry periods has greatly improved water quality and fish and wildlife estuaries above those that existed under natural conditions. Irrigated agriculture has a significant influence on quality of water in California. The principal problems are nutrients that increase the rate of eutrophication and increase salinity. Conversely, use of some streams to carry irrigation water of fairly high quality has resulted in fisheries where none previously existed. Freshwater inflows to estuaries are an important aspect of water management. Remnant freshwater wetlands are dependent upon return flows and seepage from irrigation systems. Transbasin diversions are prominent and significantly affect fish and wildlife resources.

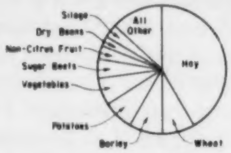
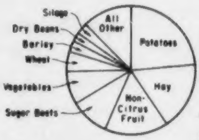
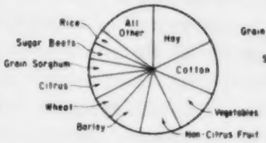
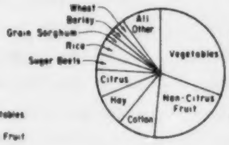
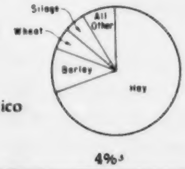
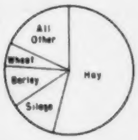
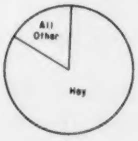
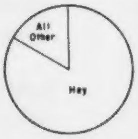
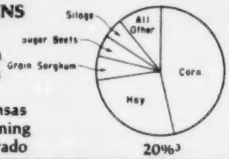
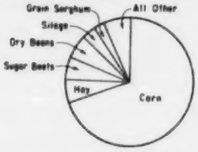
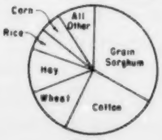
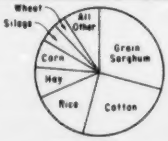
Rocky Mountain Area

Irrigated lands in the Rocky Mountain area include mountain meadows at 6,000 to 9,000 feet elevations and the intermediate valleys of the foothills, blending into the plains and plateaus at about 4,000 feet elevation. The lower the elevation is, the more intensive the irrigated cropping programs become.

Soils are very shallow, often undulating and rocky in the higher mountain meadows. In the foothills, the soils are alluvial, somewhat deeper but still often rocky. Along the eastern plains the soils are alluvial or wind-deposited and are relatively deep.

Low summer precipitation makes irrigation essential for crop production. Irrigation is dependent upon water supplies from the snowmelt runoff from the mountain streams. Storage reservoirs have been constructed to hold the high spring runoff for later use on the foothills and lower valleys. Additionally, transbasin diversions from the western Rocky Mountain slopes have been constructed in Colorado to augment the water supply of the east slope. Ninety percent of the water supply is

Table 3.—*Irrigation characteristics in the 17 western States.*

Area	Relative acreage of major irrigated crops grown	Relative value of major irrigated crops harvested	Irrigation situation	Crop growing season (days)	Consumptive irrigation requirement for alfalfa[2] (acre-ft/acre)
NORTHWEST Oregon Washington Idaho	 14%[3]	 12%[4]	Intermediate Valley[1]	120-200	2.3-2.7
			Mountain Meadow	80-120	1.3-1.7
SOUTHWEST California Arizona Southern New Mexico Southwest Texas	 22%[3]	 33%[4]	Lower Valley[1]	200-365	3.0-6.2
			Intermediate Valley	100-200	1.9-4.2
			Plains (with onfarm water supply)	200-365	3.0-6.2
INTERMOUNTAIN Nevada Utah Northwest New Mexico	 4%[3]	 1%[4]	Intermediate Valley[1]	120-200	2.0-3.7
			Mountain Meadow	80-120	1.3-1.7
ROCKY MOUNTAIN Portions of: Colorado Wyoming Montana Idaho Northern New Mexico	 5%[3]	 1%[4]	Mountain Meadow[1]	80-120	1.2-1.7
			Intermediate Valley	100-150	2.0-2.6
NORTHERN GREAT PLAINS Montana North Dakota South Dakota Nebraska Northern Kansas Eastern Wyoming Eastern Colorado	 20%[3]	 21%[4]	Plains (with onfarm water supply)[1]	160-240	1.5-2.0
			Intermediate Valley	150-200	1.5-2.0
SOUTHERN GREAT PLAINS Southern Kansas Oklahoma Texas Eastern New Mexico	 24%[3]	 12%[4]	Plains (with onfarm water supply)[1]	180-330	1.4-4.7
			Lower Valley	180-330	1.4-4.7

[1] Indicates the major irrigated acreage in the area.

[2] A widely grown crop — data indicates relative irrigation water requirements among areas. However, production per acre varies also.

[3] Total U.S. irrigated acreage.

[4] Total value of U.S. irrigated crops.

Water source	Irrigation methods	Present average irrigation efficiencies (percent)		Competitive uses	Instream flow	Water quality
		Onfarm	Off-farm Conveyance			
70% surface 30% ground water	About equally divided between sprinkler and surface (border, furrow, basin, corrugations), some trickle	25-70	60-95	Hydropower, recreation, instream flows, new irrigation and navigation	Seasonal inadequacies in streams and estuaries	Seasonal temperature fluctuations, dissolved gases and sediment
100% surface	Wild flood	25-40	55-70	Recreation and instream flows	Inadequate streamflows in dry years	Excellent
80% surface 20% ground water	Surface (border, basin, corrugations, furrow), sprinkler and some trickle	50-70	70-95	M&I, recreation, estuary inflow, instream flows, new irrigation	Severely depleted streams and estuary inflows	Salinity increases downstream
90% surface 10% ground water	Surface (border, contour ditch, furrow and corrugations)	45-65	70-80	M&I, hydropower, recreation and instream flows	Seasonal inadequacies	Good
100% ground water (severe overdraft)	Surface (border, basin, corrugations, furrow) some sprinkler and trickle	60-70	none	M&I and new irrigation	Inadequacies	Ground water good to poor
80% surface 20% ground water	Surface (border, contour ditch, furrow, corrugations), some sprinkler	35-50	70-95	Industry, recreation and instream flows	Seasonal inadequacies	Salinity increases downstream
100% surface	Wild flood	25-50	50-80	Recreation and instream flows	Localized areas with inadequate flows in dry years	Excellent
100% surface	Wild flood	25-50	50-80	Recreation, instream flows and transbasin diversion	Localized areas with inadequate flows in dry years	Excellent
95% surface 5% ground water	Surface (border, contour ditch, corrugations and furrow), some sprinkler	40-55	50-95	Power generation, recreation and instream flows	Seasonal inadequacies	Salinity increases downstream
90% ground water 10% surface (overdraft)	About equally divided between sprinkler and surface (furrow)	40-65	none	M&I and new irrigation	Seasonal inadequacies	Ground water good
90% surface 10% ground water	Surface (border, contour ditch, corrugations and furrow), some sprinkler	40-55	40-90	Industry (power generation), recreation and instream flows	Seasonal inadequacies	Warm summer temperatures and sediment problems
95% ground water (severe overdraft)	About equally divided between sprinkler and furrow and basin	50-70	none	M&I and new irrigation	Seasonal inadequacies	Ground water good to poor
50% surface 50% ground water	Surface (furrow, border and basin), some sprinkler	65-75	80-95	M&I, estuary inflow, instream flows and recreation	Severely depleted streams and estuary inflows	Low to high salinity

from surface water sources. Over 75 percent of the water is delivered to farms and ranches by irrigation organizations.

Many of the irrigation systems in this area are very old — some of the first irrigation projects in the West. Surface irrigation methods are most common. In recent years, sprinkler irrigation has increased, primarily along the east slope of this area. Inefficient irrigation has small consequence in energy consumption or water quality degradation in mountain meadows, and may provide benefits such as delay of return flows, and waterfowl habitat.

The Rocky Mountain area contains headwaters for most major river basins in the western United States. Without storage, little water is available for irrigation purposes in the latter part of the growing season of August and September. These streams can be generally characterized as trout water and may benefit from prolonged flows in late summer and fall due to irrigation return flows and reservoir releases.

The type of irrigation practices along the east slope of the Rocky Mountains, particularly in the southern part, generally result in heavily depleted streamflows and a reduction in water quality. There is some increase in salinity and nutrient loading of surface streams. While significant benefits to waterfowl and other wildlife can be attributed to irrigation development, there have been changes in wildlife and aquatic habitat through inundation from reservoirs and consumptive water use.

Southern Great Plains Area

The Southern Great Plains area is characterized by high plains and breaks on the west, rolling prairies in the center, and river valleys and forested hills on the eastern border. The northern and western sections are characterized by dry, highly variable weather, while higher precipitation is evident as one approaches the southeastern border.

The majority of the irrigated land lies in the western part known as the high plains. The soils are generally deep alluvial and wind-deposited. Irrigation in the high plains depends on a vast ground-water resource. The Ogallala Aquifer is a prime example. Over three-fourths of the irrigation water supply in the southern Great Plains comes from ground-water sources. Drought and improved efficiency of pump and motor units stimulated interest in irrigation in the 1930's. After World War II, irrigated acreage increased at a phenomenal rate. It is still growing, but at a much reduced rate, since water levels are generally declining. Declining water levels and increasing pumping costs will result in substantial reduction in supplies of water for irrigation in the high plains during the next 20 to 30 years. Less than 25 percent of the water is delivered to the farms through irrigation organizations.

About one-fourth of this area is irrigated by sprinklers, mostly center-pivot and side-roll systems. Although the total acreage irrigated is increasing slightly, the number of acres under sprinkler irrigation is increasing more rapidly.

Both the off-farm conveyance efficiency and the onfarm application efficiency for irrigation are higher than the national averages. The conveyance efficiencies are high due to the large percentage of water which is pumped onfarm directly from ground-water sources through pipe into an irrigation distribution system. High cost of pumping and declining water tables give farmers incentives for increasing onfarm efficiencies.

Depletion of surface water in the southern Great Plains has adversely affected aquatic habitats. Riparian vegetation and estuarine inflow are the most important environmental aspects of the instream flows. The monoculture cropping patterns provide little benefit for upland wildlife populations. The seasonal demands for irrigation water correlate with the low flows in the streams and cause problems in most aquatic ecosystems.

There is considerable variation in surface water quality within the area. Dissolved solids content (salinity) can vary significantly along the same river. Although irrigated agriculture does contribute to increased salinity, contributions from natural sources are more significant to the region as a whole. There are some local eutrophication problems arising from nutrient loadings from both natural and irrigation sources.

Northern Great Plains Area

Most of the northern Great Plains is characterized by flat or gently rolling topography. Primarily because of its mid-continent location, the area experiences weather that is known for its extremes and unpredictability. About 70 percent of the precipitation occurs as rainfall during the growing season. Soils of shallow alluvial deposits are found along the major watercourses, with deep wind deposits out in the plains.

Early irrigation development used surface water supplies. Extensive quantities of relatively shallow, high quality ground water underlie large portions of the area. In recent years, the development of ground water has been accelerated by the development of the center-pivot sprinkler system. Approximately 75 percent of the irrigation water supply in the northern Great Plains comes from ground-water sources. Nearly 40 percent of the acres irrigated in this area are irrigated by sprinkler. The remaining 60 percent is almost entirely irrigated either by open ditch with siphon tubes or by gated pipe. Approximately 25 percent of the water is delivered to the farms by irrigation organizations.

The streams of the northern Great Plains are generally populated by warmwater fish species. In the north, the principal impact of irrigation water withdrawn from surface flow is on instream use for fish and wildlife. In the south, data from the Second National Water Assessment (1975) indicate that the streamflow has been depleted excessively. (Figure 3.)

The relatively abundant water supplies of the northern Great Plains regions tend to dilute and mask the benefits and adverse aspects of irrigation. However, there is a general deterioration in downstream water quality for the area's watercourses due both to natural influences and the impact of irrigated agriculture. The major water quality problems are increases in suspended sediment, dissolved solids, nutrients, and some additional agricultural chemicals. The impacts of irrigation are more pronounced in the southern portion of the region (North and South Platte Rivers and Kansas River).

Water storage, conveyance systems, and groundwater withdrawal affect riparian wildlife habitat. Areas where lakes are created gain aesthetic values as well as waterfowl habitat and warmwater fisheries. Use of impoundments for recreation has augmented the local economy.

With increasing development of both surface and ground water resources, their hydrologic interrelationship is becoming increasingly important to users. One of the most significant effects resulting from man-made water and land resources developments in certain parts of the area has been the reduction of inflow to surface systems caused by withdrawals of related ground water. Ground water pumping for sprinkler irrigation is diminishing streamflows otherwise available for instream and offstream uses in parts of Colorado, Kansas, and Nebraska. Other notable effects of development include alteration of runoff and infiltration caused by land use changes and increased aquifer recharge due to surface water storage. Ground water quality has been affected in some areas due to infiltration of nitrates from fertilized irrigated land.

Irrigation Situations

This study has identified four irrigation situations which can be used to best describe the intensity of existing irrigation water management problems. They are: (1) mountain meadow irrigation; (2) intermediate valley irrigation; (3) lower valley irrigation from surface water; and (4) irrigation from onfarm water supplies. These situations are illustrated on figure 12 and are further described below.

Mountain Meadow Irrigation

Mountain meadow irrigation is practiced in areas which are high in elevation and experience a

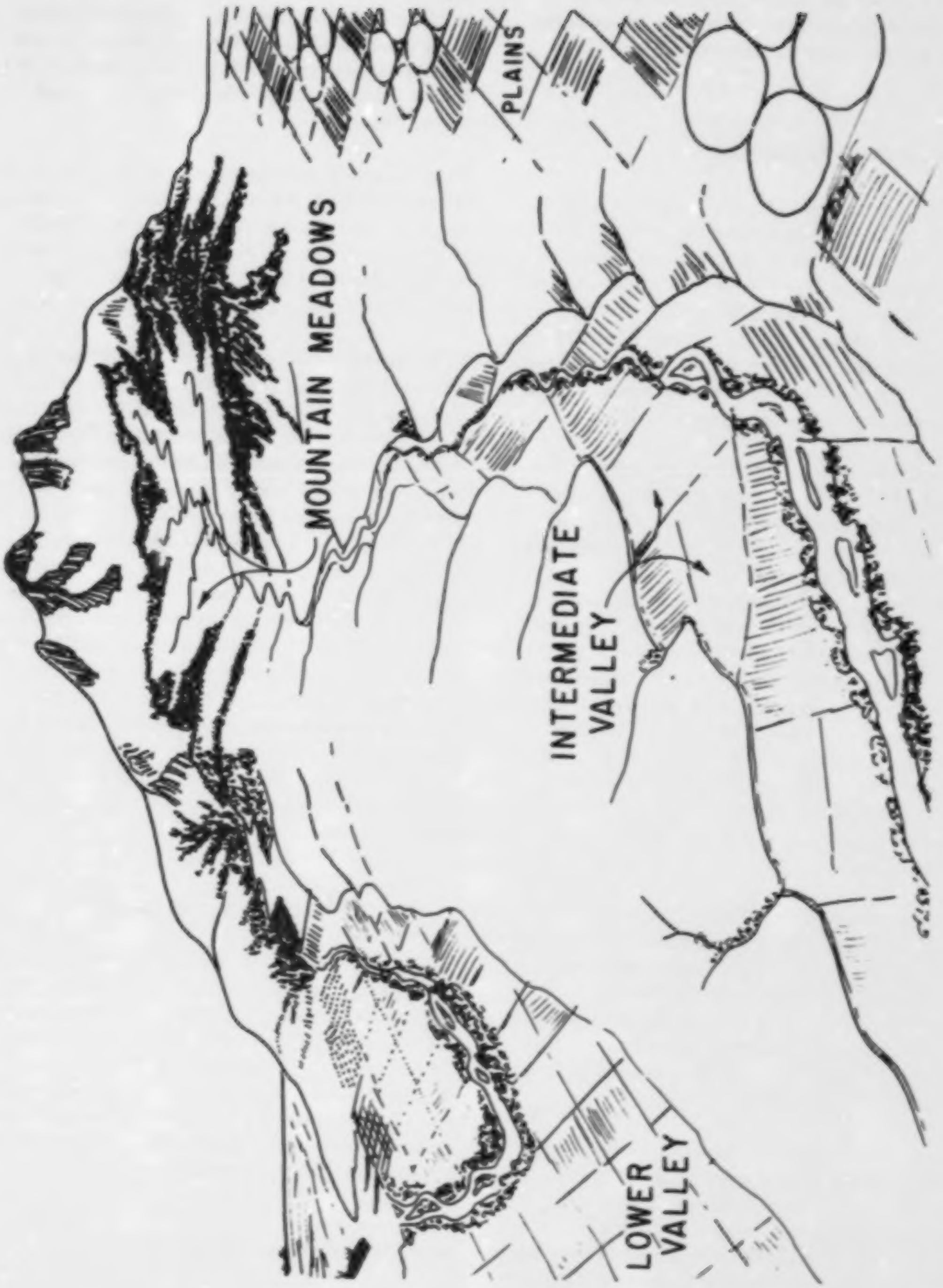

MOUNTAIN MEADOWS
PLAINS
INTERMEDIATE VALLEY
LOWER VALLEY

Figure 12.—Irrigation situations in the western United States.

very short growing season. Soils are often shallow, limiting the root zone water-holding capacity and limiting land leveling.

Irrigation is limited to grass pastures and haylands. The water supply is diverted from streams by temporary dikes and crude diversion structures. Irrigation water is generally distributed to the fields through open, unlined ditches. Field applications are usually made by wild flooding. Irrigators are hesitant to install better facilities or improve methods which would reduce diversions and return flow because of low economic returns from such investments and doubt that depletions would be significantly reduced.

Very large irrigation applications are made in high mountain areas. While seasonal consumptive use of irrigated crops is low, diversions, seepage, and return flows are very high per irrigated acre. Streamflows in these areas fluctuate considerably from very high during spring runoff to fairly low during late summer and winter. To make the best of this condition, excessive irrigation water is applied during the high runoff season to build up the ground-water table. The soil acts as a storage reservoir for the runoff and as water slowly drains out of the soil, it becomes available for both continuing downstream irrigation during the remainder of the growing season and for further downstream nonirrigation uses. The major benefits and adverse effects of inefficient water use and improper management for all four irrigation situations are summarized and compared in table 4.

Table 4. — *Significant effects of inefficient water management by irrigation situation.*

Beneficial	Mountain meadow	Intermediate valley	Lower valley	Plains (onfarm water supplies)
Increase in crop yields by extending downstream irrigation	X	X		
Maintenance of wetland wildlife habitat	X	X	X	X
Maintenance of streams for non-agricultural beneficial use	X			
Adverse				
Irrecoverable loss of water			X	X
Decrease in crop yields	X	X	X	X
Degrading water quality		X	X	X
Periodic localized over-depletion of streamflow	X	X	X	X
Excessive energy use			X	X

The Big Hole River in southwest Montana is an example of a mountain meadow irrigation situation. The growing season is less than 90 days, and only grass is irrigated, for hay. Individual irrigators or small organized groups of irrigators divert from the river, usually by annual diking following the spring runoff from snowmelt. Irrigation facilities and methods are crude and water is transported through open, unlined ditches. Although intermittent "drying up" of the stream sometimes occurs during the latter part of the irrigation season, surface and subsurface return flows maintain a streamflow a short distance downstream from where the total stream diversion took place. In winter months, a portion of the streamflow is maintained from subsurface return flows resulting from the summer irrigation practices. Irrigated crop values per acre are very low in these valleys as compared to the value of lower irrigated areas, but they do produce hay as well as winter range for the livestock and wildlife. The irrigated area supports very few people.

Intermediate Valley Irrigation

This type of irrigation is found throughout the West in valleys located between the high mountain meadows previously described and the lowlands or plains. Intermediate valleys have moderate growing seasons which limit crop production and economic capability to some extent. Water is usually supplied to these areas from natural runoff which is often stored in reservoirs. Water is diverted and transported to irrigated lands by gravity diversion structures and conveyance systems. The condition of these facilities varies considerably in intermediate valleys; however, obsolescence is common. Most conveyance systems consist of open, unlined waterways, and conservation measures such as weed control and water measurement are underdeveloped. Onfarm water applications are generally performed by surface techniques. Surface methods most common are (1) graded border, (2) contour, (3) graded furrow, and (4) corrugation. Most irrigated land is shaped to some extent; however, steep grades exist and are often not effectively irrigated. Sprinkler irrigation is increasing in some areas.

Irrigation water use and management varies in intermediate valleys. The availability of water seems to influence how well water is managed: water is applied and utilized more efficiently in areas where it is in short supply. Since water is generally in good supply, and water costs are generally low in intermediate valleys, excessive diversions, high seepage, and high return flow per irrigated acre are prevalent. These conditions appear to cause high water losses. However, return flows are reused and basinwide efficiency is not as low as is sometimes thought. There are few economic incentives for good water management in intermediate valleys. Since downstream users benefit most from water savings and improved water quality, the direct benefits to intermediate valley irrigators often do not justify the total cost of improving water use on their farms. The beneficial and adverse effects of excessive irrigation in the intermediate valleys are shown in table 4.

The Grand Valley in western Colorado is an example of an intermediate valley irrigation situation. The Grand Valley comprises approximately 60,000 irrigated acres. Water is supplied from the Colorado River, mostly by gravity diversions. Irrigation development in this area was initiated prior to the turn of the century, and the diversion, conveyance, and distribution systems are old and in many cases obsolete. Most waterways are unlined and a significant amount of seepage is experienced. Water is applied onfarm by surface irrigation. Water quality problems associated with irrigation on the project have been monitored. Canal seepage and deep percolation flow through the saline shales underlying the irrigated area, dissolving large quantities of salt and transporting it back to the river channel. The return flows are degraded for downstream use. The growing season is approximately 190 days, and principal cash crops are alfalfa, fruit, corn, and small grains.

Lower Valley Irrigation from Surface Water Supplies

The lower valley and plains areas are intensively cropped because of longer growing seasons. Many lands are double-cropped with high value cash crops, and lands have good economic capability. Irrigation development is intense, consumptive use per irrigated acre is high, and availability of water becomes a very important factor in crop production. Storage reservoirs assist in providing irrigation water to these areas. Most lower valleys have sophisticated diversion and conveyance systems, and obsolescence is not as common as in previously mentioned situations. Such features as lined canals, piped distribution systems, and automation are employed. Onfarm systems are also sophisticated. The most common methods of irrigation are graded or level border, contour levee, graded or level furrow, and sprinkler. Significant advancements in drip irrigation are being made. Onfarm tailwater recovery systems are used when water supply is limited or pumped from ground water. Thus, there may be little surface return flow.

An example of lower valley irrigation via surface water supplies is the Central Valley Project in California. Here, water is supplied by two major watersheds — those of the Sacramento and San Joaquin Rivers. Numerous storage reservoirs help provide water to nearly three million acres. Water conveyance facilities consist of lined canals and piped distribution systems to deliver water to individual farms. The total growing season in this area averages over 240 days. There are more than 200 different crops grown on Central Valley farms. The Central Valley area in California supports a large population and provides a large portion of the Nation's agricultural production.

Plains — Irrigation from Onfarm Water Supplies

There are many farms in intermediate valleys and lower valleys and plains which are irrigated by pumping water either from a ground-water supply or directly from a stream or an onfarm water impoundment. This differs from the previous situations since there are usually no off-farm water conveyance facilities. The common methods of water application in this situation are sprinkler, surface methods such as graded furrow, or borders using siphon tubes, gated pipe, and tailwater recovery systems. Irrigation has developed rapidly because of advances in technology, such as high-head pumps, sprinkler irrigation systems, and aluminum and plastic pipe.

Corn irrigation in central Nebraska provides an example of irrigation development employing onfarm water supplies. Water is pumped 100 to 200 feet from ground-water aquifers and applied with center-pivot sprinklers or furrows using gated pipe and tailwater return systems. The irrigator may use a computerized irrigation scheduling method to determine when irrigation is necessary. Irrigation efficiency is quite high since concern for energy costs and a declining water table induce irrigators to conserve on the amount of water pumped.

Chapter 2
Water Laws and Institutional Aspects

Water laws were some of the first laws adopted by States in this country through the judicial and legislative systems. Some of the water laws adopted were modeled on European law; others were entirely new concepts. Regardless, a system of water laws evolved, was adopted, and has been modified many times by the respective States to fit their changing needs.

Surface Water Doctrines

Two basic surface water rights doctrines developed in this country; the Riparian Doctrine in the humid eastern States and the Prior Appropriation Doctrine in the semiarid and arid western States.

Riparian Doctrine

The water law concepts adopted early in the history of this country were patterned after the laws in England. England recognized a public interest in those waters which were affected by ebb and flow of the tide, because the public customarily used them for navigation and fishing. All other waters — the freshwater inland lakes and streams above tidewater — were classified as private waters in which there would be no public rights. Each owner of riparian land had title to the bed of the stream which crossed his or her land, and was entitled to have the stream continue to flow in its natural condition by or upon that land. The owner could make certain uses of the water while it was upon his or her land, so long as the stream remained undiminished in quantity or quality when it left the land. Riparian rights were also attached to navigable waters, but were much restricted because of the public's right to navigation and fishing. In such streams and lakes, the beds and tidelands were owned by the Crown.

The eastern United States rather uniformly adopted the basic principles of this English system of rights as they applied to surface waters. However, riparian rights have been liberalized or changed during the years. The reasonable use concept has been applied to the riparian water right. Under the English system, diminution of water was not allowed, but the reasonable use concept allows those uses which do not "unreasonably" interfere with rights of other riparians.

Basically, the Riparian Doctrine in the eastern States as relating to irrigation is as follows:

> Only an owner of lands riparian or adjacent to a stream may make reasonable use of its waters and only on the owner's riparian land. Nonriparian lands may, under certain conditions, make reasonable use of any remaining waters. The reasonable use requirement limits the use to that quantity reasonably required for a beneficial use and prohibits waste. The right does not consist of a definite quantity of water, nor is a right gained by actual use of water or lost by failure to use it. Each riparian owner is entitled to share equitably the water in the stream.
>
> A landowner whose land borders a stream does not have an ownership right to the waters of the stream, but rather has a use right, by virtue of location; that is, a right to make reasonable use of the water and to be free from unreasonable uses by others who cause the riparian landowner harm. No riparian user, though, can take all the water of a stream to the detriment of downstream riparian users.

The Riparian Doctrine has been adopted and is being used today, as mentioned above, by most of the eastern States (east of the 95th meridian) to control and manage their surface water supplies. Mississippi and Florida have recently adopted the Doctrine of Prior Appropriation, discussed below.

In the eastern States, the major uses of water have been for transportation, industry, and municipalities. Such users have located along streams, to use the water in the channel. Essentially very little State administration is available or required under the Riparian Doctrine. However, in recent years, more and more water has been developed for irrigation purposes. The uncertainty of what constitutes reasonable use and the need for State administrative control is becoming more and more apparent. Some States are now adopting a permit program under the Riparian Doctrine. Further modification of the doctrine may become necessary as more consumptive uses of water are made. The trend is to increase public regulation of surface- and ground-water uses in this area.

Doctrine of Prior Appropriation

The law of appropriation, or Doctrine of Prior Appropriation, came into being in the semiarid and arid western States. Early water uses in the West were for mining and farming, often accomplished by trespassing on public domain. Water was a necessary resource in conducting these activities, so it was diverted and conveyed to the points of use. Water users operated in accordance with local rules and customs. When water use conflicts developed and reached the courts, the decisions rendered were generally also in accordance with the local rules and customs. In many States the Doctrine of Riparian Rights was rejected as unsuitable to the needs of the arid West. Development and settlement were synonymous with successful farming and mining, and in turn were dependent upon use of water from the streams. So the courts recognized that water could be withdrawn by anyone who could put it to a beneficial use. From this evolved the Doctrine of Prior Appropriation.

The essence of the Doctrine of Prior Appropriation is that a water right is acquired by diverting water from a watercourse for a beneficial use. The diversion requirement has been modified by many States through legislative enactment governing the use of water. The water right also carries a priority date established under the basic principle "first in time, first in right." The first person to appropriate water according to procedures outlined in State statutes and put it to reasonable and beneficial use has a right superior to, or a priority over, any later appropriators. In times of water shortages, the later "junior" appropriators may be barred from using water and exercising their rights in order to satisfy the rights of earlier priority, "senior" appropriators.

This doctrine establishes a means for an individual to obtain a right for private use of a public resource under certain conditions, as adopted by individual States through the legislative process. The right does not automatically exist by virtue of the presence of water upon, flowing through, or beneath the land. Nor does an individual establish a right to water by merely putting the water to use, but must follow the proper procedure for establishing a right under State law. Then the right is perfected only by use of the water and can be lost by nonuse and abandonment or statutory forfeiture. The appropriative right is independent of the location of the land with respect to the water. But the right is attached to a described parcel of land as prescribed by some western water laws.

The right so acquired has two legal characteristics. First, the right itself is a real property right. It is an exclusive right which, like other property interests, can be defined; it is valuable, and can be sold, transferred, mortgaged, and bequeathed. But the right differs from the right that attaches to land or chattels, for it is only a right to use a defined quantity of the resource when available. Thus, it is called a usufructuary right.

The second characteristic is that, since it is only a usufructuary right and can be exercised only when the water authorized for use under the right is available and can be put to beneficial use, there is no absolute ownership in the corpus of the water until it is applied to a beneficial use. This water is still a public resource.

All of the western States (west of the 95th meridian, including Alaska) now using this doctrine have declared in their constitutions or by their statutes that the waters within the boundaries of the respective States are the property of the public, people, or the State. Many courts have held the State to be the trustee of the water regardless of whether the public, people, or State has been designated as the owner of the water. The States have the responsibility to properly allocate and distribute the water and grant and protect the right to use water so allocated. Procedures as to how this is done in each State have been established through the legislative process. Many modifications have been made through the years by each State to meet its particular needs. Because the water is a public resource, if the right holder cannot put it to beneficial use, it must be allowed to flow past the water-right holder's diversion point to the benefit of other appropriators and right holders. However, when the water can be used beneficially, the water diverted into a delivery system becomes the personal property of the right holder until it returns to the stream or escapes the appropriator's control.

As has been implied above, beneficial use is the basis of the Doctrine of Prior Appropriation. The extent of an appropriator's right for irrigation purposes is limited by the quantity which is or may be applied by the irrigator to a beneficial use, generally not by the quantity of water actually diverted nor by the capacity of the ditch or pipeline. A diversion over and above what is reasonably necessary for the use(s) of the water cannot be regarded as a diversion for beneficial use. In other words, under the Doctrine of Prior Appropriation the irrigator cannot waste water. Beneficial use is the basis, measure, and limit of the right, and excessive use of water for any purpose cannot be regarded as beneficial use. It is a matter of States having the capability for various reasons to fully administer the doctrine. But, as becomes increasingly necessary as water demands increase, the beneficial use section of the doctrine allows for strict State administration of efficient use of water.

Usually, the term *beneficial use* is not defined *per se* by the State statutes. But, generally, it indicates any use of the water supply that is reasonable, useful, a benefit to the user, and at the same time is in the interest of the public. This flexibility of the law is necessary to fit changing needs for water through time. Several of the western States, however, have adopted as part of their statutes an allocation for irrigation water on a flow and/or seasonal use basis. Wyoming's criteria for allocating direct flow water for irrigation is 1 cubic foot per second per 70 acres; Idaho, 1 cubic foot per second per 50 acres; Kansas, 1 to 2 acre-feet per acre; Nebraska and South Dakota, 1 cubic foot per second per 70 acres or 3 acre-feet per acre. Quantities of irrigation waters were also often stated in territorial rights as issued by the courts before statehood and are part of irrigation water law in such States.

Every appropriative water right is assigned a priority date. This date is *generally* the time the water application is received by the State's water administrative office.[1] Water rights are administered according to the priority date for the distribution of the available water derived from a common source. Again, "first in time, first in right" governs.

The Doctrine of Prior Appropriation was established primarily to govern use of water and ensure an orderly means to administer the supply to those who invested their labor and/or capital. Many of the western States did not originally recognize instream flow needs as beneficial use. Water actually had to be diverted from a stream channel to be considered a beneficial use. Water laws continue to change and the concept of beneficial use is also changing as need changes in each State. Recent laws in some States recognize instream flow needs and uses for fisheries, wildlife, and recreation purposes as beneficial uses. Furthermore, some States have attempted to protect instream uses by (1) denying diversionary permits, so that an instream flow remains under the rubric of the public interest; (2) reserving water by statute from further appropriation; (3) specifically appropriating for instream purposes; or (4) allowing private or State purchase of water for such purposes.[2] Reservation, appropriation, and purchase of water for instream uses also falls within the priority systems of State water rights where adopted.

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[1] In some States the priority date is assigned in an adjudication and relates to the initiation of the physical means to appropriate water.

The eight interior western States of Utah, Idaho, Nevada, New Mexico, Arizona, Colorado, Wyoming, and Montana are almost exclusively Doctrine of Prior Appropriation States today. Some common law riparian right principles have been retained in some of these States where the courts have declared or implied that a riparian owner may apply water to beneficial use by virtue of his riparian status, so long as he does not interfere with the recognized operation of the Appropriation Doctrine.[3]

North Dakota, South Dakota, Kansas, Oklahoma, Texas, Nebraska, California, Oregon, Washington, and Alaska also recognize riparian rights. How the doctrine is used and is recognized varies from State to State. For some, the doctrine still applies to all private lands adjacent to streams, while the early riparian rights are recognized by others. However, the Doctrine of Prior Appropriation is used almost exclusively for present-day administration of water resource management in these States.

Hawaii's Law

Hawaii has been excluded from the above discussion because it has a system of water rights all its own. Throughout the State's history, the surface waters have been privately owned, attached with the ownership of the land. Therefore, whoever owns the land also owns the water. In view of the private status of the Hawaiian surface waters, there is no administrative procedure under which one may acquire a right to their use. The only ways in which a water right may be acquired are by grant from the public or private owner, prescription, or condemnation. Nor is there statewide administrative control over the distribution of water to those entitled to receive it. This is somewhat a riparian system of water law, and yet it does differ. Hawaii is presently considering the development of a system of water rights administration.

Diffused Surface Water

Rights to use surface water ordinarily are defined with respect to waters which are confined in natural watercourses, whether lakes or streams. Sometimes water is not so confined, but spreads out over the surface of the ground in no definite channel, usually as a result of rain or melting snow. When this happens, the water is classified as diffused surface water, and different legal rules apply. With respect to rights of use, anyone capturing diffused surface water on his or her land is entitled to use it, although in some Doctrine of Prior Appropriation States, a filing is required.

When the concern is not with water use, but with disposal of unwanted surface water, different legal considerations are encountered. Some States had adopted the common law rule which originally declared that unwanted surface waters are a "common enemy" which any landowner may divert or obstruct to protect his or her own property, without regard to damage caused to others. Other States had adopted the civil law rule which originally said that any particular tract of land is burdened with a drainage or flowage easement in favor of upper land, and must receive the surface water from uplands in the manner in which it flows or drains by nature.

In application today, however, these two opposing rules have largely been merged, and recent cases demonstrate a relaxation of the common law rule by preventing a landowner from negligently or unreasonably diverting surface water to the damage of neighboring property and a liberalization of the civil law by allowing landowners to obstruct or divert natural upland drainage in order to make reasonable improvements to their own property, as long as they do not act negligently or cause unreasonable damage. In short, all jurisdictions allow landowners to make reasonable use of their property, although some legal distinctions are drawn when property improvements interfere with vested rights in water use or disposition.

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[2] Lamb, Berton L. (ed.). Protecting Instream Flows Under Western Water Law: Selected Papers, Instream Flow Information Paper No. 2, (Fort Collins, Colorado: Cooperative Instream Flow Service Group, 1977.)

[3] Hutchins, Wells A., "Water Right Laws in the Nineteen Western States," Volume 1, page 192.

Ground-water Doctrines

Ground water in recent years has been developed as a significant source of water supply. The States adopted ground-water laws much more recently than surface-water laws. Although advanced technology is now becoming available regarding ground-water supplies and development, much knowledge and information is still required for wise use and management of this resource, particularly in conjunction with surface-water supplies.

When adopting ground-water laws, many of the States followed the statutes already adopted for surface water. Consequently, the formulated and adopted ground-water statutes display philosophies similar to those used for surface supplies. Laws controlling the extraction and use of ground water in many ways have now become more complex than surface-water doctrines. States are employing four different ground-water doctrines: (1) Absolute Ownership, (2) Reasonable Use, (3) Correlative Rights, and (4) Doctrine of Prior Appropriation. Because ground-water conditions are complex, classification often varies by State. More than one of the doctrines may be used, depending upon what kind of ground water is involved. The following is a discussion in very general terms of ground-water doctrines in each State.

Absolute Ownership Doctrine

The Absolute Ownership Doctrine is the English common law version of the Riparian Doctrine, which simply states that the landowner can withdraw as much water as desired from beneath owned land without liability to neighbors in so doing. The doctrine gives absolute ownership of the ground water beneath the land to the landowner. The water is deemed to be part of the soil. States using this doctrine include Texas, Louisiana, Arkansas, Missouri, Minnesota, Indiana, Ohio, Pennsylvania, Vermont, Massachusetts, Connecticut, Maine, New Jersey, Rhode Island, South Carolina, Georgia, Alabama, Mississippi, and parts of California.

Reasonable Use Doctrine

As more knowledge was acquired about ground water and its flow under the ground surface and how interferences caused by users affect landowners above the same aquifer, many of the States modified the Absolute Ownership Doctrine to limit the landowner to a reasonable use. This new concept restricts the landowner's rights to water from those of absolute ownership to that of reasonable use, recognizing equal rights of all to ground-water resources.

States employing this system of law include Arizona, Nebraska, Iowa, Illinois, Michigan, Kentucky, Tennessee, Florida, North Carolina, Virginia, Delaware, West Virginia, Maryland, New York, New Hampshire, and Wisconsin.

Correlative Rights Doctrine

The State of California has gone one step further with the Reasonable Use Doctrine in formulating the Correlative Rights Doctrine. The landowner's use must not only be reasonable, but must be correlated with the use of others, particularly during times of water shortage. When supplies become insufficient because of a drought or the drawdown effect, each landowner is entitled to water in proportion to the percentage of owned land in relation to all other lands overlying the ground-water supply. The doctrine is also followed in Oklahoma and somewhat in Colorado and Nebraska. In Colorado, SB-213 allocates water in a confined aquifer based on one percent of the available instorage supply annually.

Doctrine of Prior Appropriation

As in surface water supplies, under this doctrine the ground water is considered the property of the State and the resource is subject to appropriation for beneficial use through a priority system with principles very similar to those for surface waters.

States using this doctrine are Washington, Oregon, Idaho, Nevada, Montana, Wyoming, Utah, Colorado, New Mexico, North Dakota, South Dakota, Kansas, Alaska, and, in part, California.

Hawaii's Law

The Hawaiian legislature passed a ground-water use act in 1959 which provides for regulation by a State Commission of withdrawals of ground water from areas designated by the commission. Even with commission authority to regulate ground water, however, no water rights system *per se* has really been established in Hawaii, as in mainland States. But as indicated in the surface-water section, Hawaii is studying its water law system at this time.

Rights in Return Flow

Under Riparian Doctrine

Riparian lands benefit from irrigation return flows. The water that returns to the stream which had been diverted upstream and is not consumed becomes part of the natural streamflow to be shared by riparian owners. The riparian rights of such lands entitle the owners to the natural flow of the stream, including such portions of the natural flow diverted upstream as are allowed to flow back into the stream after use. The fact that such water has been used on upstream lands does not deprive it of the character of natural flow when it returns to the stream from which diverted. The riparian user may enjoin an upstream user from depriving the riparian owner of return flows upon which he has been depending for the enjoyment of his riparian right. This does not necessarily mean that a downstream junior right holder can bar the upstream users from improving the efficiency of their operations. The test would be the effect of the change on the downstream right.

Under Doctrine of Prior Appropriation

In areas where the Doctrine of Prior Appropriation is used, the downstream flows on many streams have been augmented by seepage and return flows from irrigation of upstream lands. This is a common phenomenon in irrigated valleys, and much development has been predicated wholly or partly upon the continued existence of such flows. The increased flow does not consist of new water (unless brought in from another watershed), but is the reappearance of water previously diverted. The water may reenter the stream through surface or subsurface flow. In any event, if the irrigator does not lawfully recapture the return flow water, it becomes a part of the stream and accrues to the benefit of downstream claimants in accordance with their rights to the natural flow.

Return flow waters from a diversion under an appropriated right are a part of the streamflow from the time the waters escape from the premises or works of the appropriator, provided they would ultimately return to the stream system from which originally diverted if not artificially intercepted. Consequently, the waters belong to that stream system and are subject to the rights of appropriators thereon in the order of their priorities. An attempt to recapture the water by the appropriator after it leaves the boundaries of the land to which it was appropriated is not permitted under the Doctrine of Prior Appropriation. In other words, such water belongs to the stream, even before it commingles with the water of natural flow. An appropriator who historically has not consumptively used all diverted water generally cannot change the methods of application to totally consume all the water if the change adversely affects downstream users.

Virtually all interstate compacts and court decrees between States address return flows. For example, the 1957 decree between Colorado and Wyoming concerning the Laramie River states that Wyoming desires to ensure the continuation of return flows from the water diverted to the Colorado meadowlands, and to eliminate the threat that the meadowland appropriations may be diverted out of the basin of the river.

The 1945 North Platte decree among Nebraska, Wyoming, and Colorado states that the return flow from the Kendrick Irrigation District in Wyoming shall be deemed to be "natural flow water" when it reaches the North Platte River, and subject to the same diversion priorities and use as any other natural flow in the stream.

Compacts and decrees generally apportion among the States the beneficial consumptive use of the waters of the stream system (e.g., the Colorado River Compacts). The Supreme Court has defined "beneficial consumptive use" as diversions from the stream less return flow thereto.

Water Administration

The Riparian Doctrine system required very little State administration until recent years because of small depletions of water for transportation, domestic, and industrial uses. But with recent increases of irrigation consumptive uses, many of the eastern States are adopting administrative procedures to enforce the reasonable use aspect of the law through permit systems or other means. As irrigation development increases, administrative responsibilities of each affected State will increase. Essentially, a priority and property rights system is developing in the eastern States.

In the States using the Doctrine of Prior Appropriation, water resources agencies have been established to administer water development, use, and management. This agency is given responsibility to administer the permits and water rights as defined in each State's statutes, in the interest of the public. A person(s) desiring to use or appropriate water must file an application for a permit with the proper State official or State water agency. The agency in most States is empowered to issue a permit with a priority date, or deny it on various grounds according to State statute.[4] Denial is generally related to a determination of the lack of unappropriated water (and in some States, water set aside for instream purposes) and an interpretation of the public interest.

While each State's water administration agency normally has a considerable number of duties, most statutes provide for essentially a threefold approach to water administration: (1) appropriation, (2) adjudication, and (3) distribution. The above includes keeping all records associated with the tasks.

Many of the western States have a board or commission that supervises and has decision-making powers while assisting the water administration officer. The commission or board generally also has authority to adjudicate water rights. At least five States in the West, New Mexico, Colorado, Utah, California, and Wyoming may adjudicate water through the State court system.

State statutes provide relatively strict enforcement powers to the water administration agency for proper distribution of water under the priority system and beneficial use concept. Water commissioners or field staff are generally assigned these tasks under the supervision of the water administration officer.

Abandonment and Forfeiture

The Doctrine of Prior Appropriation also provides for abandonment and forfeiture of water rights. Appropriation rights are dependent upon continued beneficial use of the water. One way in which an appropriation water right may be lost is for the owner of the right to discontinue use of the water with intent to abandon the water right. No particular time period is required for an abandonment to become effective since the only requirement for abandonment is the act of nonuse with an intent not to resume use. However, it is not always easy to prove subjective intent of one who discontinues use of the water, and statutes in some States create a presumption of intent to abandon when nonuse persists for a specific period of time. In some States presumption of abandonment has the same practical effect as the doctrine of forfeiture.

Forfeiture occurs when the owner of an appropriation water right fails to use the water for the period prescribed by statute. The most common period of nonuse for purpose of forfeiture is 5 years, although some States have periods as short as 2 years. Unlike abandonment, the doctrine of forfeiture is not concerned with the intent of the owner of the water right, because the fact of nonuse alone is sufficient to cause a forfeiture. However, while nonuse for the statutory period is a prima facie forfeiture, the owner of the water right might be able to show that the nonuse was not the owner's fault, thereby delaying or negating forfeiture decisions.

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[4] In Colorado the State District Court issues water rights decrees; i.e., permits the appropriation of water.

Generally, for forfeiture to occur, nonuse must be continuous for the statutory period during times when the water was available for use.

Interstate Compacts, Court Decrees, and International Treaties

Historically, State boundaries were fixed without much evident regard for hydrologic features created by nature. (A few interstate boundaries follow the course of streams; others follow the divides separating one watershed from another.) While some drainage basins lie entirely within a single State, no State boundaries correspond with a drainage basin except for that between Idaho and Montana. Much of the water used in the United States comes from sources shared by more than one State. With stream systems crossing State boundaries, and with the increased demand for use of water, problems in allocation of the interstate water and the administration of water rights can arise. In anticipation of such problems, several States have entered into interstate compacts or have requested court apportionment of the affected waters. Where these agreements result in interstate compacts, the compacts must be consented to by the Congress. Where States could not agree on the allocation of water, courts have been asked to allocate the supply for them by court decree.

The earliest uses of interstate compacts in the water resources field occurred under the Articles of Confederation when such agreements were employed to deal with boundary problems and navigation and fishing rights in interstate waters. Interstate compacts generally were not used for any other water-related purposes until 1922 when the Colorado River Basin Compact was agreed upon to apportion the beneficial consumptive use of a part of the waters of the Colorado River system between the upper and lower Colorado River Basin States. Since then, over 30 compacts dealing with assorted water problems in a variety of ways have been adopted. The Supreme Court has encouraged the use of such compacts. Similarly, the Congress has indicated that it would look favorably upon compacts dealing with flood control and water quality.

Existing water compacts may be grouped into four general categories: Water allocation, pollution control, flood control and planning, and comprehensive regulatory and project development.

In a way, all four types of compacts do have an influence on irrigation water use and management practices, but water allocation compacts primarily are those which have addressed irrigation.

The general purpose of all water allocation compacts (21 by 1978) has been to provide a means of equitable apportionment of waters of interstate streams so that development of waters might proceed unhindered by demands of neighboring States for their relative rights in the common streams. Primarily, such compacts have provided certainty of waters of interstate streams to both upstream and downstream States regardless of their stage of development, although generally the lower States have developed much more rapidly than the upper States.

No pollution compacts addressing irrigation water quality as such have been adopted in the United States. Those which relate to industrial and municipal pollutants have been adopted almost exclusively by the eastern States. However, one compact has been agreed upon in the West between California and Oregon on the Klamath River, addressing water quality which may affect irrigation water management.

With regard to international treaties, the United States Government may obligate itself to take certain action. The treaty obligations are binding because the United States Constitution makes them part of the supreme law of the land. An example of such a treaty is one with Mexico on the Colorado River. Others may require protection of fish and wildlife habitat within the contiguous United States. Such treaties affect the interstate and intrastate allocation of water.

Local Water Institutions

As opportunities for irrigation development by individuals in the West became exhausted, or people recognized potential for developing large tracts of land and quantities of water, attention was turned to institutional arrangements to allow people to organize into groups to carry out such projects. The major water organizations used for group irrigation development are unincorporated mutuals, incorporated mutuals, irrigation or other water districts, and companies or associations. According to the 1969 U.S. Census of Agriculture, over 75 percent of the land irrigated in Wyoming, Colorado, Utah, Idaho, Montana, and Washington has water delivered through some type of group water organization. Over 50 percent of the land irrigated in Oregon, California, Arizona, New Mexico, North Dakota, and South Dakota is served by group organizations. Nevada, Nebraska, Kansas, Oklahoma, and Texas have less than 25 percent, and the eastern States less than 5 percent of irrigated land to which water is supplied by organizations.

With more complex facilities involving high construction costs, these organizations expedited development by combining private, State, and Federal capital and labor. State legislation has provided for the creation and operation of many types of districts for irrigation water use and management — mostly single-purpose districts such as irrigation districts, drainage districts, watershed districts, water improvement districts, water control districts, and ground-water control districts. In recent years, State statutes have been adopted to provide for multiple-use water districts, such as water conservancy districts and natural resource districts which may comprise an entire watershed and combine the operation of many single-purpose districts, and to provide a means to develop and manage water on a multipurpose basis. Thus, combined water development and management for irrigation, municipal, recreational, industrial, and other needs can be provided by such a district.

Powers of the organizations vary with the duties or purpose of the group. These powers may include fixing water prices; collecting assessments; planning, constructing, and maintaining waterworks; and allocating district water. Such powers are enunciated in enabling statutes of each State. But, as with individuals, surface- and ground-water supplies are still basically allocated on a priority basis and quantities regulated according to the beneficial use concept. Water users in many of the organizations often "pool" their water rights during water-short years.

Ground-water management districts in Nebraska, Kansas, Colorado, Oklahoma, and Texas provide the means for managing the water supply beneficially other than on a priority basis. However, Nebraska enacted legislation which prohibited the formation of any additional ground-water conservation districts after July 1, 1972, and recent legislation requires the dissolution of existing ground-water districts no later than 90 days after January 1, 1982. This has resulted in a de-emphasis of single-purpose districts. In Nebraska, ground-water management responsibilities are being assumed by multipurpose natural resource districts. These districts provide the opportunity to manage all water supplies conjunctively.

Federal Role in Water Resources

While State rules of water law define the nature and limit of water rights, the Federal role in water resources cannot be ignored. In some instances, Federal powers or property rights may take precedence over water rights created under State law.

Federal Regulatory Power

Under the commerce clause of the United States Constitution, the Congress has the power to regulate interstate and foreign commerce. This power has two aspects. First, the Supreme Court has held that navigation is a function of commerce, and commerce on all navigable interstate waters is subject to regulation by the Congress. This regulation extends not only to vessels, but to dredging or excavating in such water, construction, discharge of pollutants, flood control projects, and other measures to regulate streamflow. Even further, the Congress may regulate the nonnavigable flow of tributaries contributing to and sustaining the flow of navigable waters, because if the tributaries were seriously depleted downstream navigation might be endangered or impaired. Thus, with the possible exception of a closed basin where water does not drain into an ocean, most surface waters appear to be subject to congressional regulation in aid of navigation.

The second aspect relates to commerce. Under this function, the Congress may regulate any activity touching upon or affecting interstate commerce. The Congress has never exercised this power to the ultimate, but if it should, it seems likely that every water use could be interpreted to affect interstate commerce — however remotely or indirectly — and could be subject to Federal controls.

Federal Proprietary Rights

In the eastern States, where the Federal Government owns land bordering on water, it also owns riparian rights in accordance with the laws of the respective States. In the West, the Federal property interest is much greater. The western States were carved from public domain which the United States acquired by purchase and cession. The United States obtained ownership of all land, minerals, and water, subject only to vested private rights at the time of acquisition. Since then, private rights in water were created under territorial law prior to statehood and under State law after statehood, all with the express consent of Congress.[5] However, the Federal Government retains a proprietary interest, sufficient to shield withdrawal of such water from further appropriation under State law, and to reserve it for use in connection with withdrawn Federal reserved lands.

When Federal lands are withdrawn or reserved for specific purposes, either by legislation or executive order without any mention of water, the courts have implied that unappropriated water is reserved in an amount sufficient to satisfy the purposes of the withdrawal or reservation. Treaties between the United States and Indian tribes and executive orders reserving lands for Indian use, as well as statutes reserving lands for Indian use, similarly reserve by implication sufficient water for use by the Indians on the reservations. Water use entitlements of most Federal reservations have not been determined or quantified. It is the position of many States that the Congress should require that all Federal water rights be acquired from the States in accordance with State law.

A conflict between State-created water rights approved by the Congress and Federal reserved rights is developing in the West. There are many issues still to be resolved in regard to these rights. Court actions are in the process of addressing the Federal reserved rights issues. For example, in a recent Supreme Court decision — New Mexico v. United States (Mimbres Valley), No. 77-510, July 3, 1978 — was that the limited purpose for which the Congress authorized the creation of a national forest provides no support for the claim for reservation of minimum instream flows of water for aesthetic, recreational, and fish preservation purposes.

General Welfare

In addition to regulatory power and property rights of the Federal Government, the Constitution authorizes the Congress to act in aid of the general welfare. This is, in essence, a spending power; but it authorizes the Congress to proceed with any water project or program which will aid or promote the welfare of the people. In so doing, the Congress may exercise its sovereign power, such as eminent domain, to acquire land and water necessary to complete a project or program.

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[5] Because of the manner in which it entered the Union, Texas differs from other States which were formed from the public domain.

Reclamation Act

The Federal Government became a substantial partner in the development of western arid land with the enactment of the Reclamation Act of 1902. This act provides for water development and irrigation works construction which benefits public and private lands. The acquisition of water rights under Reclamation projects (section 8 of the act) provides that (1) water laws within the State are to remain unaffected, (2) rights acquired and vested under State law must be protected, (3) water rights are to be tied to the lands irrigated in the project, (4) the Secretary of the Interior may only proceed with a Reclamation project after giving full consideration to the conformity to State law as it relates to irrigation development, and (5) beneficial use is the measure of the water rights obtained for the project development.

The Clean Water Act of 1977

The Clean Water Act of 1977 (Public Law 92-500 as amended by Public Law 95-217) strengthens the shared responsibilities between the Federal and State Governments (Environmental Protection Agency (EPA) and individual States) for implementation of water quality management programs as provided by the act. Congressional intent for maximum delegation to the States to carry out water quality programs is clearly expressed in the act, but provides for Federal action if a State does not assume the responsibility. Table 5 shows the major sections in the act which are relevant to irrigation water management.

Primary responsibility for implementation of sections 106, 208, 303, and 404 rests with the individual States. However, the EPA has review and approval authority with regard to the programs. A major change in the Clean Water Act was that irrigation return flows were dropped from the point source definition, and National Pollution Discharge Elimination System permits are not now required unless a State so wishes. Responsibility for dealing with irrigation return flows was placed under section 208.

Table 5. — *Major sections of the Clean Water Act of 1977 relevant to irrigation water management*

Section of the Act	Topic
101 (e)	Public Participation in Water Pollution Control
101 (g)	State Jurisdiction Shall not be Impaired
102 (d)	Analysis of Relationship Between Water Quality and Water Quantity Programs
104 (d)	Research New and Improved Methods of Preventing, Reducing and Eliminating Pollution from Agriculture
105 (e)	Grants for Agricultural R&D Projects
106 (a)	Grants for Pollution Control Programs
106 (e)(1)	Water Quality Monitoring and Reporting
208	Areawide Waste Treatment Management
208 (j)	Agricultural Cost Sharing
303	Water Quality Standards and Implementation Plans
304 (k)	Interagency Agreements of Implementation of 208 Plans
305	Water Quality Inventory
404	Permits for Dredged or Fill Material

The Rural Clean Water Program (section 208(j) of the Clean Water Act) is a new program which authorized a technical assistance and cost sharing program with rural landowners to implement best management practices to control nonpoint source pollution for improved water quality. This program is administered by the Secretary of Agriculture through the Soil Conservation Service, with the concurrence of the Administrator of the EPA. To qualify for cost sharing funds, the conservation practices and measures must be part of an approved section 208 water quality management plan.

Impacts this legislation will have on irrigation water use and management have not been fully realized because very few water quality management plans which include irrigated lands have reached implementation status. Many of the States established a water quality administration agency separate from the existing water quantity administration agency. Conflicts between State and Federal administrative authorities over quantity and quality control may result and will need to be reconciled. In the West where irrigated agriculture is by far the largest consumer of water, how the quantity and quality control laws are effectively commingled in each State will need to be of top priority.

Water Resources Planning Act

The Water Resources Planning Act of 1965 established the Water Resources Council to coordinate Federal and State/regional water planning activities.

Title I of the act called for a national assessment of water and related land resources to be conducted periodically to guide national water development and management programs.

Title II of the act authorized the establishment of regional, Federal, and State river basin commissions, of which six have been chartered across the northern tier of States, to develop coordinated comprehensive joint water plans for the river basins.

Title III provides funding to the States to build their capabilities to participate in multiagency planning and to formulate State water plans.

The act and the resulting programs have promoted the opportunity to bring together varying technical expertise from Federal and State water use agencies and provide a broader understanding and perspective of water uses and needs of the agencies involved.

Water Conservation and the Doctrine of Prior Appropriation

The Doctrine of Prior Appropriation in the West is both praised and criticized as the method for allocation, distribution, and administration of water resources.

Criticism of the Doctrine

In the June 22, 1976, GAO report,[6] it is indicated that water rights influence the efficiency of irrigation water use. The following statement is made:

> "In some areas, the nature and priority of irrigators' water rights influence efficiency of water use. Farmers may hesitate to change their irrigation practices because of fears of interference with their water rights or possible loss of water rights. Where water rights are tied to the land, there may be no legal way for a farmer to use any water he may 'save' on additional acreage. Thus, his incentive to irrigate efficiently may be reduced. More strict interpretation and enforcement of the beneficial use doctrine contained in many State water rights laws could encourage more efficient practices."

Secretary of the Interior Cecil D. Andrus expressed concern in a letter to President Carter, April 1977, over the "use it or lose it" syndrome that seems to exist with western irrigators.

> "The processes of developing new projects and water doctrines have combined to create a 'use or lose' syndrome, which, when coupled with generous Federal financing, has led to a water development system which does not adequately consider the conservation of the precious resource."

Thus, it is said that irrigators may divert as much of their total allotment of water as possible to protect their right, resulting in over-irrigation and creating large quantities of return flow waters. However, courts in several States have held that the irrigator need not divert the full amount entitled under the right or decree to avoid forfeiture.

Other national reports also indicate that water laws are an important factor in influencing efficient uses of irrigation water. The September 2, 1977, GAO report[7] makes reference to the 1973 National Water Commission report; the following is recommended for attention:

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[6] Report to the Congress, Comptroller General of the United States, "Better Federal Coordination Needed to Promote More Efficient Farm Irrigation," June 22, 1976.

[7] Report to the Congress, Comptroller General of the United States, "More and Better Uses Could be Made of Billions of Gallons of Water by Improving Irrigation Delivery Systems," September 2, 1977.

". . . The States in water-short regions should enforce existing laws to limit water use to beneficial need and thus prevent wasteful application of water and unreasonable transmission losses.

"The appropriation States should quantify 'beneficial need' and 'reasonable efficiency' for particular areas in order to reduce water waste.

"States in water-short areas should adopt doctrines and procedures to encourage voluntary actions to improve efficiency of water use. Water supply projects should not be authorized by the Congress until evaluations are made with respect to the efficiency of use of presently developed supplies in proposed project areas, and until a report is made on the prospects and desirability of satisfying existing shortages in any particular area by water-savings practices in lieu of further project development."

The Doctrine of Prior Appropriation has been criticized also because it is based upon the use of chronological priorities. The first person to appropriate, no matter where located on the stream system, always has the first priority to take available water; the order of priorities thus has random scattering over the length of the stream. Administratively it is difficult to efficiently distribute the waters within a stream system.

It is possible that during times of shortages, water is distributed by priority dates and all the shortages could be imposed on the junior water right holders instead of being shared by all appropriators.

Some other portions of the Doctrine of Prior Appropriation or administrative procedures that are referred to as discouraging efficient use of irrigation water include: (1) beneficial use is not specifically defined as it relates to inefficient irrigation, (2) property rights concept of the doctrine establishes a water right in perpetuity instead of a review of the water right and its duty after a fixed term of use, (3) many States recognize only quantity of flow and not quality in determining beneficial use, and (4) several State water records are inadequate for administering an efficient irrigation water use program, such as records showing quantity and quality of water by basins, and actual acres irrigated in relation to the water rights.

Advantages of the Doctrine

Even though portions of the Doctrine of Prior Appropriation are criticized, most will agree that in its basic form it is still the most fitting legal structure for the wise management of water because of its characteristics of certainty, continuity, flexibility, and identity.

Some portions of the Doctrine of Prior Appropriation and its administrative procedures which are often referred to as an advantage for encouraging efficient use of irrigation water are:

1. Based on beneficial use, the doctrine is flexible enough to provide State administrators with the authority to act upon all the above criticisms and bring about efficient use of irrigation water where necessary. To do so, however, will often be very expensive, requiring many more water measuring and control structures, administrative and field personnel, and other measures to carry out the program. The provisions to do so are in the law. Administration of the law is the key.

2. Changes in use or transfer of irrigation water to lands that can be more efficiently irrigated is possible under most western State laws, requiring only the approval of the State water administration agency. The agency may not permit such a change without specifying that the consumptive use will not (1) exceed the beneficial consumptive use of the original purpose, (2) impair other vested rights, or (3) restrict a change in the point of diversion.

Recent Changes in State Water Laws and Administrative Procedures

Laws, as in the past, will continue to evolve in each State as competing uses demand. Specific changes will come about automatically, but will only be realized through painstaking effort. All this will occur with the understanding that vested water rights are property rights entitled to protection through constitutional due process. Vested rights cannot be taken, impaired, or destroyed in the name of better water management without payment of just compensation, except by exercise of the State police power.

Changes are taking place in State water laws to fit changing needs and encourage efficient use. Some recent changes in State water laws and administration include:[8]

1. Wyoming's law allowing the change of use or transfer of irrigation water.
2. Washington's provisions that do not allow condemnation of agricultural water rights when certain criteria are followed by the agricultural water user.
3. Duty of water concept as in Nevada's law.
4. Placing the burden on water users to help the State keep water records current as required in Idaho and Oklahoma.
5. New Mexico's statutory recognition of a reasonable degradation for water use as an essential element of beneficial consumptive use.
6. Periodic check on water waste and quality impacts in Kansas.
7. Ground-water management districts in Kansas, Colorado, Oklahoma, Washington, and Texas, with authority to require efficient use of irrigation water (such as well-spacing, water meters, and tailwater recovery systems).
8. Wyoming's law permitting the establishment of ground-water control areas to efficiently manage ground-water resources.
9. Laws providing for the establishment of multiple-use districts to manage total water resources, as in Nebraska, Wyoming, and Colorado.
10. Texas' periodic evaluation of outstanding permits, resulting in cancellation of unused permits.
11. California and Washington administratively integrating water quantity and quality control.
12. Colorado's Water Data Bank, a compilation of tabulations for all water decrees, with eventual elimination of unused rights.
13. California's Department of Water Resources directed by their water code to prevent waste, unreasonable use, unreasonable method of use, or unreasonable method of diversion of water.
14. Instream flow needs recognized as beneficial uses in Colorado, Montana, Idaho, Oregon, and Washington.

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[8] Radosevich, George E., "Western Water Laws and Irrigation Return Flow," Resources Administration and Development, Inc. Fort Collins, Colo., p. 18. August 1978.

Chapter 3
Programs Related to Irrigated Agriculture

Irrigated agriculture was achieved in the mountainous West in spite of a short water supply. Improvements have taken place as technology improved and economics made them feasible. There are numerous economic incentives for irrigation farmers and ranchers to improve the efficiency of their operations. Better water use and management make possible a reduction in labor requirements, better utilization of fertilizers, energy savings, and higher crop production. This chapter describes those State, local, and Federal programs which are available to or influence landowners and operators in irrigation enterprises.

State Programs

Irrigation investments made by farmers and ranchers with their own resources and with assistance of ongoing programs have a beneficial effect on the small and large communities of all 17 western States. Table 6 shows the type of programs which each State has in force. All western States are developing or keeping up-to-date water plans and carrying out various surface water, ground water, and water management investigations. All are responsible for administering, according to State law, water rights and water regulation programs, including those associated with compacts, agreements, and court decrees. All States have funds for research and education, mainly through State universities and usually in cooperation with Federal programs.

Some States, notably California and Idaho, have recently carried out studies and activities on water conservation which have been very helpful in preparing this report. Arizona is in the process of publishing a report.

Table 6. — *State programs relative to irrigation water use and management — 17 western States.*

State	Planning and investigations	Technical assistance	Research	Education and demonstration	Construction or cost-sharing	Loans	Water administration and regulation
Arizona	X		X	X			X
California	X	X	X	X			X
Colorado	X		X	X		X	X
Idaho	X		X	X		X	X
Kansas	X		X	X			X
Montana	X		X	X			X
Nebraska	X		X	X	X	X	X
Nevada	X		X	X			X
New Mexico	X		X	X	X	X	X
North Dakota	X		X	X			X
Oklahoma	X		X	X			X
Oregon	X		X	X			X
South Dakota	X		X	X			X
Texas	X		X	X			X
Utah	X	X	X	X	X	X	X
Washington	X		X	X	X	X	X
Wyoming	X		X	X	X	X	X

Idaho, Nebraska, New Mexico, Utah, Washington, Colorado, and Wyoming have substantial funds available for grant or loan programs, primarily revolving construction loan funds which are available at low interest or interest-free for up to 40 years. An example is the State of Wyoming which has made $60 million available since 1955 for assistance to farmers and ranchers for the construction of irrigation improvements. These programs have been very successful and are used effectively in cooperation with Federal programs. While State funds under some of these programs have been used to develop additional irrigated areas, the primary uses have been to improve irrigation systems, rehabilitate older systems, construct reservoirs to provide more adequate seasonal water supplies, and change to the type of onfarm irrigation systems which are more water and cost efficient. Detailed information on funds available specifically for the improvement of irrigation water use and management is difficult to obtain.

Most of the projects carried out under the above programs fall in the $75,000 to $200,000 range. They represent a shift in emphasis — from projects which in the early years of the programs were primarily aimed at development of new water supplies — to projects which currently involve the construction of facilities permitting better control, management, and greater efficiency of water use in existing irrigated areas.

The revolving fund programs have been in existence for varying periods. The one of greatest longevity is that of the State of Washington, established in 1919 with funds appropriated by the legislature. In 1972, the voters of the State authorized the issuance of general obligation bonds of $75 million for water supply facilities. Of this total, $25 million were earmarked for loans or grants for agricultural water supply improvements and developments. To date, the fund has provided about $16.5 million to agriculture, and the funding for fiscal year 1978 is $4.5 million.

The program of the State of Utah was established 30 years ago, and periodic appropriations by the legislature have provided $19 million. With repayments, a total of $30 million has been available from this fund. Average annual funding from this source is about $1.25 million, but the 1978 legislature authorized an additional $25 million in bonding authority to meet a backlog of high-priority projects which have accumulated over the past few years. Current aggregate revolving loan expenditures in the 17 western States from continuing State funding programs for water projects of this nature are estimated to be in excess of $20 million per year.

Of perhaps greater significance than present State funding is the apparent acceleration in the initiation of these programs and increased levels of appropriations in recent years. A revolving fund was authorized in Idaho as recently as 1969, and in Colorado in 1971. The Wyoming legislature has recently earmarked $100 million of mineral severance tax income (to be received over a period of years) for a State water development program fund.

A unique and perhaps significant aspect of the Idaho State Water Plan is the nature of the legislation which created the program and the language of the policy directive. The act took the form of an amendment to the constitution, and the legislation specifically requires that conservation of water use be considered and encouraged. Under the Idaho revolving development fund program, conservation and improvements in water use efficiency are eligible project purposes, and water conservation is a major element of consideration in allocating loan funds.

Most of the States carry out some research or studies in irrigation water management to improve water use efficiency. Examples of studies underway include Idaho's Section 208 Irrigation Incentives study, the Improved Water Use Incentives study and the Water Rights Accounting study. Irrigation efficiency research is being done in Nebraska and Kansas. Nevada and Utah also have carried out crop response studies to various levels of water supply and soil moisture. California funds extensive research in the efficient use of water and energy in agriculture.

Success by several States in administering irrigation water use and management programs has been demonstrated and indicates that States can play a greater and more effective role in any new national thrust to improve water use and management in irrigated agriculture.

Local Programs

It is estimated that the private annual investment for 1977 is $710 million for improved irrigation facilities. Private annual expenditures for the past 30 years have averaged $234 million in 1977 dollars.

Other local programs responsible for promoting water conservation which have been in operation since the mid-1930's are those of the State Soil Conservation Commissions and the local Conservation Districts. There are 1,159 districts in the 17 western States and 2,896 in the United States. Many are organized on county boundaries, but others include basin or sub-basin areas. These districts, under the direction of elected, unsalaried commissions or boards, are charged with developing plans and priority programs and giving technical assistance to the farmer or rancher who requests assistance. The districts are supported by county and State funds to carry out their responsibilities. With few exceptions, these programs have not been adequately funded to achieve their full potential. However, the conservation districts have been the local organizations through which most of the technical assistance has been channeled to individual landowners from Federal programs.

Irrigation districts and companies spend millions of dollars annually to operate, update, and improve water delivery systems. These entities have instituted water conservation measures and programs with landowners in their districts. Sometimes Federal programs become a part of the district program. There are nearly 8,000 water system delivery organizations in the 17 western States. Local directors hire management employees who are responsible for water delivery according to law. Annual maintenance and improvement charges are large enough to cover management costs plus the annual costs of improvement projects on their systems. In Utah, water shareholders in a typical company pay an annual O&M cost of $3 to $5 per acre. Individuals or companies carrying on system improvement typically pay an additional levy of from $8 to $12 per acre.[1] For a farming unit of 300 irrigated acres, the average improvement and O&M cost of $14 per acre creates an annual cost of $4,200 per year.

Landowners' participation with conservation programs of the Department of Agriculture on irrigation measures in the western United States during 1977 totaled about $18 million. On the prevailing average cost-share basis of 20 percent Federal to 80 percent private, the private irrigator added $72 million for system rehabilitation and improvement. (Actual Federal cost-sharing rates are sometimes higher, but landowners more often than not install units in addition to those for which cost-sharing is received.)

Through the past 30 years, an average of 450,000 acres of sprinkler irrigation has been installed annually by private operators, with little State or Federal financial assistance. Private costs range from $350 to over $900 per acre.[2] An even more efficient method is the drip system of irrigation now being installed on fruit and specialty crops at a cost equal to or greater than that of sprinkler systems.

Federal Programs

Even though there had been irrigation development in the West since the mid-1800's, the first major Federal assistance program in irrigation began with the passing of the Reclamation Act of 1902. Some prior assistance had been provided to the Indians. The Reclamation Act, as amended, has resulted in the development of irrigation service for about 20 percent of the irrigated land in the western United States. Assistance varies from projects mainly to develop the total water supply and distribution systems for lands previously undeveloped for agricultural crop production, to many recent projects chiefly to supplement water supplies or reorganize distribution systems on existing irrigated areas.

In addition to the Reclamation Act administered by the Bureau of Reclamation and the Federal projects for Indians, water and related land resource development programs of other Federal agencies provide some assistance in irrigation project development. These include the multiple-purpose water resource projects of the Corps of Engineers and the small watershed program of the Department of Agriculture. Most of these Federal programs do not stand alone, but are initiated by or coordinated with subdivisions of State governments such as irrigation districts or other natural resource or special-purpose districts.

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[1] Utah Division of Water Resources.

[2] "Irrigation Costs," Leaflet No. 2375. University of California, Division of Science.

A second kind of assistance in irrigation came about as a part of national agricultural programs. Because these programs are directed primarily to assist farmers in dealing with resource and financial problems and to bring about a more productive and stable agricultural economy, farmers with irrigated land are just as eligible for assistance as those practicing dryland farming. Many of the programs are designed to deal with the specific land and water resource problems of the individual farmer, and in irrigated areas the primary concern is with the use and management of water. Thus, the research, education, technical assistance, cost-sharing, and loan assistance programs of the Department of Agriculture are directed to improving onfarm irrigation practices and related cultural and management practices. This assistance is available to nearly all irrigated land as desired by individual land operators.

A third set of Federal programs affecting irrigated areas are those which have as a primary concern the protection and improvement of the environment. These programs give attention to fish, wildlife, and other natural resource values in new water development areas as well as to those associated with existing irrigated lands and facilities. Water quality as related to runoff or return flow is a major concern in irrigated areas, and programs are directed both to controlling some types of activities and to improving facilities and management on irrigated as well as nonirrigated land.

Generally, most Federal programs have not come about because of irrigation alone, but as a result of other broad national concerns. These concerns have included settling the West; using our vast natural resources; stabilizing the agricultural economy; assisting the individual farmer in times of drought, flood, and other natural disasters; reducing soil erosion; protecting endangered species; improving water quality; and more recently, a growing concern for efficiently utilizing the Nation's water resources. Because irrigated agriculture is the largest consumer of water, programs dealing with these national concerns have been directed to irrigated areas and facilities.

Description of Current Federal Programs

Some 35 Federal programs involving about 10 separate agencies have been identified as providing assistance to irrigation organizations. About $175 million of Federal funds are spent annually, indicating that the Federal Government already has helped improve the use and management of water in irrigated agriculture. This is in addition to the major construction programs of the Bureau of Reclamation and the Bureau of Indian Affairs involving about $550 million annually. Also, there are Federal programs which indirectly relate to irrigation water use and management. Most of the programs are environmentally oriented and estimates of the portion of the funding for these programs which might be considered related to irrigation management are not available.

The objectives of Federal programs vary greatly and include planning, technical assistance, research, education and demonstration, cost-sharing, grants, loans, regulations, and acquisition of land and water for environmental purposes. Most of these programs are carried out cooperatively with State agencies and institutions, local governmental bodies, and/or individuals. Nearly one-half of all programs require and receive coordination at the State and local levels; but some long-standing programs providing assistance directly to landowners are coordinated at the local level through committees or special-purpose districts. Many programs carried out by the Department of Agriculture, the Environmental Protection Agency and the Fish and Wildlife Service are applicable to all irrigated lands in the Nation. However, the Bureau of Reclamation programs are limited to the 17 western States and generally only to those lands which are included in Federal reclamation projects (about 25 percent of the irrigated lands in the 17 western States). The programs carried out by the Bureau of Indian Affairs apply only to Indian reservation lands.

In addition to the Federal reclamation projects, a number of programs are applicable to specific or project areas only. Some of these are the Great Plains Conservation program, the Watershed Protection and Flood Prevention program, the

Resource Conservation and Development program and the Colorado River Basin Salinity Control program. Information on the ongoing Federal programs providing assistance to irrigation water use and management is summarized in table 7. Table 8 shows similar information on the programs related to but not providing assistance directly to irrigation. A number of programs which provide assistance on water storage, conveyance structures, conveyance management, onfarm structural practices and onfarm management measures are about equally divided — 12 to 15 for each type of measure. An information statement on each program was provided by the Federal agencies.

The agencies indicated that some changes and improvements were needed in the programs to make them more effective in improving irrigation water use and management. Only 13 programs were noted as needing no changes at this time. A questionable response was that only 6 were in need of better coordination between agencies. As might be expected, 16 were appraised as needing more funds. It was indicated that 7 require additional personnel, 5 need some legislative changes, 8 need policy changes, and 10 could be more effective if program priorities were adjusted.

Planning Assistance

Some degree of planning is provided by 17 programs. Six of these are programs of the Department of Agriculture, primarily the Soil Conservation Service. Four are programs of the Bureau of Reclamation. Two are administered by the Bureau of Indian Affairs. Five are environmental programs carried out by the Fish and Wildlife Service and the Environmental Protection Agency. Most of these programs are designed to achieve some degree of water conservation in irrigated agriculture. However, the river basin studies carried out by the Department of Agriculture in cooperation with State agencies are being directed more toward special water problems; data collected in these studies can be used to analyze basin-wide irrigation water use and management problems and to evaluate possible improvement programs. Similar opportunities exist in the Bureau of Reclamation's Total Water Management program and in the Section 208 Water Quality Management plans sponsored by the Environmental Protection Agency. Similar objectives are being achieved as a result of the salinity control studies in the Colorado River basin. Water conservation as an objective can be incorporated in the project plans of the Bureau of Reclamation and the Small Watershed and Resource Conservation and Development plans of the Department of Agriculture. The Environmental Protection Agency is including water conservation as a priority item in its programs. The Bureau of Reclamation evaluates existing project water use as a part of investigations of new projects and studies of rehabilitation and betterment potentials.

Index of Agencies and Programs

Programs Providing Assistance in Irrigation Water Use and Management

Department of the Interior

Construction Program — Bureau of Reclamation
Construction Program — Bureau of Indian Affairs
Small Reclamation Projects — Bureau of Reclamation
Rehabilitation and Betterment Program — Bureau of Reclamation
Operation of Indian Programs — Bureau of Indian Affairs
Distribution System Loans — Bureau of Reclamation
Colorado River Basin Salinity Control Program, Title I — Bureau of Reclamation
Total Water Management Studies — Bureau of Reclamation
Colorado River Water Quality Improvement Program — Bureau of Reclamation
Irrigation Management Services — Bureau of Reclamation
Review of Maintenance Program — Bureau of Reclamation
Water Resources Research — Office of Water Research and Technology
Water System Automation — Bureau of Reclamation

Table 7.—*Summary of ongoing Federal programs providing assistance in irrigation water use and management.*

Program identification	Est. annual funding[1]	Type of assistance									Cooperate with			Program applic. to			Major program needs to be more effective[2]							Eligible measures						Agency(ies)[3]
		Planning	Technical	Research	Education — demonstration	Cost sharing or Fed. const.	Grants	Loans	Regulation	Land and water acquisition	State agency of instit.	Local organization	Individuals	Federal projects only	All irrigated lands — West	All irrigated lands — U.S.	Priority adjustment	Policy changes	Legislative changes	More personnel	Increased funding	Better coordination	No change	Water storage	Conveyance — struct.	Conveyance — mgt.	Onfarm — struct.	Onfarm — mgt.	Environmental prot.	
USDI	($1 mil)																													*USDI*
Construction Program	505.0					X						X		X									X	X	X	X			X	BR
Construction — Irr. Proj.	44.4	X				X											X	X			X				X		X			BIA
Small Rec. Projects Act	18.7							X				X			X			X	X			X		X	X				X	BR
Rehab. & Betterment Prog.	8.0							X				X		X				X	X						X					BR
Oper. of Indian Prog.	7.0	X	X			X						X	X							X	X						X	X		BIA
Distribution System Loans	5.7					X						X		X									X		X					BR
CRB Salinity Control - I	2.7	X	X	X	X	X				X	X	X	X										X			X	X	X	X	BR (SCS, SEA)
CRB Water Qual. Imp. Prog.	1.2	X	X			X					X	X	X										X		X	X		X	X	BR (USDA)
Irrigation Mgmt. Services	1.1		X								X	X	X				^				X	X				X		X	X	BR
Review of Maint. Prog.	0.5		X								X	X		X									X	X	X					BR
Water Resources Research	0.3			X							X					X	X				X									OWRT
Water System Automation	0.19			X	X											X							X	X	X					BR
Aquatic Plant Control	0.16			X	X						X	X				X					X	X				X				BR (FWS, SEA)
CRB Salinity Control - II	0.08	X	X									X	X										X			X		X	X	BR (SCS, SEA)
Conduit System Program	0.06			X	X											X							X		X					BR
Total Water Mgmt.	1.73	X	X									X			X								X	X	X	X	X	X	X	BR
Water Systems Mgmt.	0.03					X					X	X			X						X					X				BR
EPA																														*EPA*
Waste Treatment Mgmt. (Sec. 208)	10.4	X			X	X	X		X		X	X	X			X	X				X	X							X	EPA
R & D	1.25		X	X	X		X				X	X	X			X				X	X								X	EPA

USDA																														
Cons. Oper. Prog.	29.1	X	X									X	X			X				X	X	X		X	X		X	X	X	SCS
Soil and Water Loans	28.8							X					X			X			X					X			X			FmHA
Agricultural Cons. Prog.	18.1		X			X							X			X	X	X	X		X				X		X		X	ASCS (SCS)
Emergency Cons. Measures	10.0		X			X							X			X							X				X		X	ASCS (SCS)
Watershed Prot. Flood Prev.	5.2	X	X			X		X			X	X	X			X	X	X						X	X	X	X	X	X	SCS (FS, FmHA)
Irr. & Dr. Assoc. Loans	4.5							X				X				X							X	X	X					FmHA
Resource Cons. & Dev.	3.7	X	X			X		X				X				X		X			X			X	X	X			X	SCS (other USDA)
Snow Surveys	3.2	X									X				X								X							SCS
Water Bank Program	3.1		X			X				X	X		X			X	X	X											X	ASCS (SCS)
Cooperative Extension	2.4				X						X	X	X			X				X	X	X								SEA
Coop. River Basin Studies	2.2	X									X	X				X	X				X			X	X	X	X	X	X	SCS (FS, ESCS)
Research, Land & Water	2.1			X							X					X				X	X				X	X	X	X	X	SEA
Soil Surveys	2.1		X								X	X	X			X	X													SCS
Great Plains Cons. Prog.	1.6	X	X			X						X	X				X				X			X			X	X	X	SCS
CRB Salinity Control - II	0.5	X		X	X						X	X							X		X						X	X	X	SCS (SEA, BR)
Cooperative Research	0.4			X							X					X	X				X									SEA
Econ. Research & Analysis	0.15			X							X					X					X									ESCS
WRC																														
Level B and Special Studies		X					X				X					X														WRC[4]

[1] Portion applicable to irrigation water use and management [2] Limited to three (X) per program. [3] Responsible agency (cooperating Federal Agencies)
[4] Council members are listed in the narrative; amount of funds not available.

Index of Agencies and Programs - Continued

Aquatic Plant Control Methods and Canal Environments — Bureau of Reclamation
Colorado River Basin Salinity Control Program, Title II — Bureau of Reclamation
Open and Closed Conduit System Program — Bureau of Reclamation
Water Systems Management Workshop — Bureau of Reclamation

Environmental Protection Agency

Areawide Waste Treatment Management (Section 208) — Clean Water Acts
Research and Development (Sections 104 and 105, PL 92-500) — Clean Water Acts

Department of Agriculture

Conservation Operations Program — Soil Conservation Service
Soil and Water Loans — Farmers Home Administration
Agricultural Conservation Program — Agricultural Conservation and Stabilization Service
Emergency Conservation Measures — Agricultural Conservation and Stabilization Service
Watershed Protection and Flood Prevention — Soil Conservation Service
Irrigation, Drainage and Other Soil and Water Conservation Loans (Association Loans) — Farmers Home Administration
Resource Conservation and Development — Soil Conservation Service
Snow Surveys and Water Supply Forecasting — Soil Conservation Service
Water Bank Program — Agricultural Conservation and Stabilization Service
Cooperative Extension (Smith-Lever Act) — Science and Education Administration
Cooperative River Basin Studies — Soil Conservation Service
Research on Conservation and Use of Land and Water Resources, and Maintaining Environmental Quality — Science and Education Administration
Soil Surveys — Soil Conservation Service
Great Plains Conservation Program — Soil Conservation Service
Colorado River Basin Salinity Control Program, Title II — Soil Conservation Service
Cooperative Research (Formula Funds, Hatch Act) — Science and Education Administration
Economic Research and Analysis — Economics, Statistics, and Cooperatives Service

Water Resources Council

Level B and Special Studies

Programs Related to Irrigation Water Use and Management

Environmental Protection Agency

Federal Interagency Agreements (Section 304(k) of PL 92-500)
Federal Facilities Pollution Control (Consistency) (Section 313 of PL 92-500)
Clean Lakes (Section 314 of PL 92-500)
Safe Drinking Water (Section 1423(e) of 92-500)

Department of the Interior

Endangered Species Program — Fish and Wildlife Service
Land and Water Development Program — Fish and Wildlife Service
Cooperative Instream Flow Service Group — Fish and Wildlife Service
National Wetlands Inventory — Fish and Wildlife Service
Fish and Wildlife Restoration — Fish and Wildlife Service
National Water Use Data Program — Geological Survey
Fish and Wildlife Coordination Act — Fish and Wildlife Service

Department of Agriculture

Rural Clean Water Program — Soil Conservation Service

Council on Environmental Quality

National Environmental Policy Act

Table 8.—*Summary of ongoing Federal programs related to irrigation water use and management.*

Program identification	Est. annual funding[1]	Type of assistance									Cooperate with			Program applic. to			Major program needs to be more effective[2]							Eligible measures						Agency(ies)[3]
		Planning	Technical	Research	Education — demonstration	Cost sharing or Fed. const.	Grants	Loans	Regulation	Land and water acquisition	State agency or instit.	Local organization	Individuals	Federal projects only	All irrigated lands — West	All irrigated lands — U.S.	Priority adjustment	Policy changes	Legislative changes	More personnel	Increased funding	Better coordination	No change	Water storage	Conveyance — struct.	Conveyance — mgt.	Onfarm — struct.	Onfarm — mgt.	Environmental prot.	
EPA																															
Interagency Agreements (Sec. 304(k))																X													X	EPA
Federal Consistency (Sec. 313)									X		X	X	X			X						X							X	EPA
Clean Lakes (Sec. 314)		X	X			X	X				X					X						X							X	EPA
Safe Drinking Water (Sec. 1423(e))							X		X		X	X	X										X						X	EPA
USDI																															
Endangered Species Program		X	X	X	X	X			X		X	X				X				X	X								X	FWS
Land & Water Devel. Prog.		X	X							X	X	X		X						X	X		X	X		X			X	FWS
Coop. Instream Flow Service Group			X	X	X						X	X	X			X		X		X	X					X			X	FWS (others)
Nat. Wetlands Inventory			X								X					X	X				X								X	FWS (others)
Fish & Wildlife Restor.		X	X	X			X			X	X					X				X	X			X		X			X	FWS
Nat. Water Use Data Prog.			X			X					X	X				X				X	X									USGS
USDA																															
Rural Clean Water Prog.			X			X					X	X	X			X							X				X	X	X	SCS (ASCS, EPA)
CEQ																															
Nat. Env. Policy Act		X														X							X						X	CEQ

[1] Portion applicable to irrigation water use and management

[2] Limited to three (X) per program.

[3] Responsible agency (cooperating Federal Agencies)

Planning assistance is available to individual landowners in the development of onfarm water conservation plans through the Conservation Operations and Great Plains Conservation program of the Soil Conservation Service. Similar assistance is provided in the Wellton-Mohawk Irrigation and Drainage District under Title I of the Colorado River Basin Salinity Control Act.

Some planning assistance or funds are available to States in programs administered by the Fish and Wildlife Service for endangered species, land and water development, and fish and wildlife restoration. Those programs can be coordinated with the irrigation water conservation plans.

Most States are developing or keeping up-to-date State water plans. Many of these plans, developed separately or with varying degrees of assistance or coordination with Federal agencies, contain sections on irrigation water use and management or water conservation. The most recent State efforts on this subject have been in connection with drought abatement plans for 1976 and 1977.

Another program which provides assistance in water resources planning is that of the Water Resources Planning Act which provides for a Water Resources Council made up of Federal agencies; for funding to the States to assist in developing water resources plans; and for the river basin commissions, a joint Federal-State venture for water resources planning coordination. The Council is made up of representatives of the Secretaries of the Interior, Agriculture, Army, Transportation, Energy, Commerce, Housing and Urban Development, and the Administrator of the Environmental Protection Agency.

Framework studies carried out by river basin commissions identify the problems, resources and needs of a river basin. More detailed studies define the programs and actions for smaller areas or sub-basins. These studies follow guidance provided by the Water Resources Council and consider economic, environmental, and conservation viewpoints. The commissions, made up of State and Federal agencies, have been responsible for arriving at a common point of view and improved coordination of programs resulting from these studies.

Technical Assistance

Technical assistance is available through some 22 programs, with most being available directly to individuals. Several programs provide assistance to local organizations, and a few assist State agencies in fish and wildlife or water data programs. The three major programs providing technical assistance to irrigators are the Conservation Operations and Soil Survey programs of the Soil Conservation Service and the Irrigation Management Services program of the Bureau of Reclamation. Other programs providing technical assistance to irrigators are connected with cost-sharing programs such as the Agricultural Conservation program, Great Plains Conservation program, Resource Conservation and Development, Small Watershed Protection and Flood Prevention program, and the Wellton-Mohawk salinity control program. It is estimated that $30 to $35 million of Federal funds are used annually for technical assistance in the installation of onfarm physical and management practices to improve irrigation water use and management.

Technical assistance is provided to local organizations in planning and installing works of improvement or management measures. Many of the programs mentioned above assist local organizations as well as individuals. The review of maintenance program is carried out by the Bureau of Reclamation to help irrigation districts which are managing the facilities in Federal projects.

Research

An estimated $4.1 million of Federal funds are spent annually on research related to irrigation water use and management. Much of the water quality research by the Environmental Protection Agency and others on irrigation return flow and salinity problems is also applicable to water conservation.

Of the $4.1 million, more than one-half is associated with the research projects of the Agricultural Research office, Science and Education Administration, Department of Agriculture. This research is directed to the development of advanced irrigation practice methods, equipment, and systems to efficiently utilize soil, water, and energy resources and increase agricultural productivity. Cooperative research funds of the Science and Education Administration are made available to land grant universities on a matching basis to carry on research related to efficient irrigation water use and management. Economic research related to irrigation is performed by the Natural Resource Economics Division of the Economics, Statistics, and Cooperatives Service, Department of Agriculture.

The Bureau of Reclamation funds research through the Colorado River Basin Salinity Control Program, Title I, relative to onfarm measures and irrigation water management. It also has research programs on new and improved methods and materials for the conveyance of water, more effective and efficient methods of controlling aquatic weeds in irrigation systems, and development of automatic and remote control systems for water storage and conveyance facilities. The Office of Water Research and Technology, Department of the Interior, also funds research related to irrigation at designated universities in each State as a part of the Water Resources Research Act of 1964.

Education and Demonstration

About 10 programs provide some input to education and demonstration. However, it is estimated that no more than $3 million of Federal funds are used in these programs annually. The major organization providing this assistance is the Cooperative Extension Service of the Science and Education Administration, and States and counties. Program methods and techniques employed include public information meetings and training workshops, field demonstration and tours, irrigation equipment shows, 4-H training programs, publications, news media, and individual onfarm visits. Federal funds for additional assistance are provided through the salinity control programs, the water systems workshop of the Bureau of Reclamation, the Environmental Protection Agency Section 208 areawide waste management program, and a number of demonstration efforts related to research projects.

Cost-sharing Assistance or Direct Federal Construction

The two major programs of direct Federal construction are the irrigation projects of the Bureau of Reclamation and the irrigation program of the Bureau of Indian Affairs. These two programs use an estimated $550 million annually. However, the amount varies considerably from year to year. It is not known how much involves improvements in existing irrigated areas as compared with facilities for new areas. The Soil Conservation Service administers two programs which cost-share with local organizations in water storage or distribution system improvements. Some of the reservoirs and other facilities constructed by the Corps of Engineers also provide water for irrigation.

Some Federal programs provide funds to cost-share with individual irrigators in the installation of irrigation facilities or practices. These are estimated at $40 million annually, of which more than one-half is provided through programs of the Agricultural Stabilization and Conservation Service.

Loans

Seven programs provide loan assistance to individuals and organizations to finance costs of installing irrigation improvements. Federal loans total about $65 million each year. The Bureau of Reclamation's distribution system loans and rehabilitation and betterment loans are available to irrigation districts operating Federal projects. Its Small Reclamation Project program is applicable to irrigation organizations throughout the 17 western States. The Farmers Home Administration operates two major loan programs. One provides soil and water loans to irrigators for onfarm measures, and the other is available to irrigation associations. It also administers watershed and resource conservation and development loans to help finance the local share of costs in these federally assisted projects. In total, the combined loan programs appear well designed to meet local financing needs not available from private institutions.

Other Programs Related to Irrigation

Several national programs dealing with fish and wildlife habitat and other environmental concerns have implications for irrigation. Changes in irrigation water use and management can have impacts on endangered species, wetlands, water quality, and instream flows. The Fish and Wildlife Service programs on these subjects affect land and water resources of concern to irrigators and irrigation organizations and require coordination at the local level. A number of the programs authorized in the Clean Water legislation and carried out by the Environmental Protection Agency will provide coordination between water programs with participation at the State and local levels, and will assure consideration of water quality goals.

Several programs involving data collection and interpretation also are important in irrigation water use and management. These are the national water data program of the Geological Survey, the weather data and forecast programs of the National Weather Service, and the snow survey and soil survey programs of the Soil Conservation Service. Data and interpretative information from all of these programs are quite helpful to planners, irrigators, and irrigation district and company managers.

For some of the programs, there has already been established a high degree of cooperation among the Federal agencies. An example would be the Colorado River Basin Salinity Control program. Cooperation among agencies is essential in carrying out the Rural Clean Water program authorized by the Clean Water Act, PL 92-500 as amended by PL 95-217, and in accomplishing the goals of that act.

Needed coordination is not limited to Federal agencies. The water resources, conservation, and environmental agencies of the State must also coordinate and cooperate to achieve the objectives of their individual and mutually related programs.

However, many cooperative programs already exist among the Federal, State, and local agencies. There are few irrigation projects of any magnitude where the following agencies do not mutually work together. Examples are the programs of the Department of Agriculture with the conservation commissions and conservation districts; the Bureau of Reclamation and irrigation districts; the Environmental Protection Agency and State water quality agencies; the Department of Agriculture and the State extension services; and the Geological Survey and the State water agencies.

Nearly 75 percent of the programs identified are indicated as being applicable to environmental protection as part of the program mission. Better integration of environmental programs, especially habitat and water quality programs, with irrigation programs appears to be needed.

Chapter 4
Inefficiencies - Causes and Results

The 17 western States are considered in this chapter. They include most of the arid and semiarid regions of the country and contain 90 percent of the irrigation development. Irrigation in the eastern area is discussed in chapter 6.

Causes and results of low irrigation efficiencies are presented under two headings — those factors reducing effective use of water and the results of ineffective use of water.

It is recognized that the irrigator has some incentive to strive for high efficiency in the use of water. However, there are situations over which the irrigator has no control that continue to make the job difficult. These situations include fluctuations in climate (drought and floods), inadequacy of the water supply when needed, and lack of flexibility in the management of an agricultural enterprise. There are times when the water efficiency is low due to the existence of these types of uncontrollable situations. Irrigation districts also may have constraints on their operations which can affect onfarm as well as conveyance efficiencies.

Factors Reducing Effectiveness of Irrigation Water

As water is delivered through the off-farm conveyance system (canals and laterals), some of it seeps into the soil, is used by vegetation, and evaporates; some is required for operational purposes and is spilled into wasteways. Much of this also occurs with onfarm systems, except the operational water becomes surface runoff. In most western watersheds there exists a successive use regime in which water delivered but not consumed by crops finds its way back to the stream and is rediverted by a downstream user. Such successive uses may occur any number of times. Thus, it cannot be assumed that all water not utilized by a crop on a particular field is lost. In addition to the irrigatio- return flows that find their way back to the stream, some may return to a ground-water aquifer and be reused through ground-water pumping.

This pattern of irrigation water use results from the physical conditions of the off-farm and onfarm irrigation systems or the improper management of these systems. In addition, the use and management of irrigation water is influenced by institutional and social factors. Table 9 summarizes the degree to which the factors exist in each irrigation situation described in chapter 1.

Off-farm (Conveyance System)

Physical Factors. — The primary conditions that cause conveyance losses can be attributed to: (a) permeable canals, (b) obsolete, inadequate, or improperly maintained facilities, and (c) excessive vegetative growth. Seepage through unlined canals is the main contributor to conveyance losses. Canals constructed in sand, gravel, or fractured rock generally have higher seepage rates than those in silts or clays. Seepage rates are proportionately greater for canals with intermittent flows than for those under continuous operation. Many canals are already lined.

Obsolete, inadequate, or improperly maintained facilities create a situation of poor control and management of water throughout the off-farm conveyance system which affects the onfarm management of water. For example, review of the Wellton-Mohawk (Arizona) Irrigation and

Table 9. — *Factors reducing effectiveness of irrigation water.*

Factors	Intensity[1] within each situation[2]			
Conveyance system	Mountain meadows	Intermediate valleys	Plains (Onfarm)	Lower valleys
Off-farm				
Physical system	SL	M	NA	SL
Some examples: Obsolete, inadequate, or improperly maintained facilities, unlined ditches Inflexible facilities Excessive vegetative growth in and adjacent to canals				
Ineffective management	SL	M	NA	M
Some examples: Operation of facilities Water deliveries, timing, and quantity No flow measurements Record keeping Lack of policy Inadequate enforcement of existing policy Shortage of personnel Water management in place of labor				
Onfarm				
Delivery system	M	S	M	M
Some examples: Inadequate water measurement devices Unlined ditches Improper ditch maintenance Improper location or alinement of ditches Obsolete system Inflexible facilities				
Field application system	M	S	M	S
Some examples: Improper land shaping Improper relationships of slopes, run lengths, border widths, discharge rates Improper design of sprinkler or drip systems (pumping capacities, pressures, nozzle sizes) Method of application not suited for soils or slopes				
Ineffective water management	M	S	S	S
Some examples: Improper timing of irrigations Incorrect application amounts Improper scheduling of water Excessive use of cheap water to save labor				

[1] SL — Slight; NA — Not applicable; M — Moderate; and S — Severe.

[2] See chapter 1 for description of irrigation situation

Drainage District system[1] indicated that the district could reduce seepage with a program of repair and maintenance. The accuracy of measurement of farm water deliveries could be improved by reconditioning structures. Minor structural modifications to district laterals would increase the dependability of supplying design flow rates to farms, affording the opportunity to achieve higher onfarm efficiencies.

Excessive vegetative growth in and along canals interferes with the delivery of irrigation water, causes seepage and transpiration losses, causes sediment to accumulate, and contributes to structural failure and to poor operation of the canals. In addition, excessive growth clogs drainage ditches, limits fishing and boating on recreation waters, degrades fish habitat, and provides breeding places for insects.

Management Factors. — Improper management of a conveyance system causes low operating efficiency of the system and affects onfarm efficiencies. If the method of water delivery from the conveyance system is not coordinated with the onfarm irrigation needs, low efficiencies will result.

Water management practices will vary from district to district, depending on district facilities, onfarm irrigation methods, climate, and crops grown. A water district must have and follow an operational policy in order to manage its water supply and deliver water to its irrigators in an efficient and equitable manner. Without water measurements, a district cannot determine its available water supply or effectively control the water flowing through the conveyance system to keep operational losses to a minimum. Also, water cannot be delivered in quantities requested by the water users, nor can the efficiency of the system be determined.

Institutional and Social Factors. — The factors that inhibit correction of conveyance losses include: (1) existing water laws or court decrees, (2) water prices, (3) environmental conflicts, (4) financial capabilities, and (5) social attitudes as related to land use.

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[1] "Measures for Reducing Return Flows from the Wellton-Mohawk Irrigation and Drainage District," Special Report, The Advisory Committee on Irrigation Efficiency, September 1974.

Existing water laws in the West are based on the Doctrine of Prior Appropriation (see chapter 2). In some instances, an appropriator may divert all of his allotment to maintain his water right. Where irrigators divert more than is beneficially needed, over-irrigation, excessive spillage, surface runoff, and deep percolation may occur, with concurrent effects on instream flows and water quality. Irrigators may have little incentive to reduce applications because, under most existing laws, they cannot apply the water to new land if there are prior appropriations. Allowing irrigators to apply water to additional land would increase net stream depletions and reduce return flows to downstream users. The existing water laws that affect irrigators likewise affect the conveyance organization that is in most cases managed by the irrigators.

The rate schedules used to assess or charge irrigators in irrigation districts for the cost of water delivered in many cases are constant and do not discourage excessive use of irrigation water. In a number of irrigation districts an excess water charge is levied, based on an acre-foot per acre use. The per-acre-foot charge increases as the use increases. This has been only partially effective in encouraging efficient use of water since the total water charge is generally one of the minor production costs.

Environmental conflicts related to irrigated agriculture cause some irrigation improvement programs to be reduced or eliminated. Restrictions in the use of certain chemicals have an impact on the chemical control of weeds in the conveyance system. Water resource entities may be reluctant to improve their conveyance systems because of conflicts related to the reduction or damage of wildlife habitat. The cost of mitigating adverse impacts of some rehabilitation programs may be large enough to discourage their implementation.

Irrigators who own and operate the conveyance systems may not be able to finance or recover the investment cost necessary to implement efficiency improvement measures. Costs of construction, operation, and maintenance are borne by the irrigators through water charges or tax assessments. Irrigators are often reluctant to assume additional expense for rehabilitation or improved operation of the conveyance system, especially during times of depressed farm incomes. Irrigators often feel that most benefits of conveyance system improvements accrue to downstream users.

Urban development is competing for land as well as for allocation of surface and ground water supplies. About 1.1 percent of the land area of the West is devoted to urban development.[2] Agricultural land converted to urban development may subsequently receive water from an alternate supply. In these cases the water that was once supplied to this land for irrigation may be diverted to other, less efficient uses or to land ill-suited for irrigation. When the agricultural water supply remains in the urban development, the delivery and management of water may become difficult, and the conveyance system less efficient.

Onfarm

Physical Factors. — Onfarm physical conditions that contribute to inefficient water use and management other than those caused by non-uniformity of soils can be separated under onfarm delivery systems and field application systems. Variability within fields of soil intake rates, water holding capacities, and erosion resistance contributes to inefficient water use.

Onfarm delivery system problems include unlined farm ditches, lack of measurement structures, poor farm layout, and improper maintenance. Excess water may be delivered to the onfarm systems to offset seepage in farm ditches. This excessive demand for water aggravates the off-farm seepage and management problems as well.

The method of water application affects irrigation efficiency, particularly if the method is not suited to soil or topographic conditions. Surface irrigation of steep or non-uniform slopes may result in poor application uniformity, soil erosion, excess surface runoff, and deep percolation. Sprinkler irrigation on fine-textured soils produces surface runoff if the intake rate of the soil is exceeded by the application rate of the sprinkler.

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[2] "Westwide Study Report on Critical Water Problems Facing the Eleven Western States," USDI, April 1975.

A surface application system must be designed and operated correctly to obtain good water management. The relationships between field slope, field length, soil characteristics, and water flow must be balanced to achieve uniform application with minimum deep percolation and surface runoff. For example, the slope and water flow rate may be acceptable, but the length of the field may be too long for the soil conditions.

Management Factors. — Management factors include lack of soil moisture data and improper timing of irrigation, lack of adequate flow measurements, incorrect application amounts, and lack of adequate facilities to control water. The timing of irrigations and the application amounts may vary because of water availability, other farm activities, or an off-farm job which requires the irrigator's attention, resulting in lower irrigation efficiencies.

Irrigation water deliveries can frequently be reduced if water applications match plant growth requirements. To prevent ineffective water use, irrigation applications must be carefully balanced with precipitation and crop water use so that the water-holding capacity of the soil within the root zone is not exceeded. Water infiltrated in greater amounts than the root zone can hold results in deep percolation. The irrigator may be unaware of this condition, particularly on sandy soils, because there is no immediate visual evidence. To avoid such inefficient irrigation, a system capable of uniform water application is needed at the time of irrigation. The irrigator also needs to be knowledgeable about plant water requirements and soil water-holding capacity. A recent poll in Idaho[3] indicates that most irrigators would use excess water rather than risk economic loss from under-irrigating crops. The survey also indicated that farm operators turned most often to friends and relatives for information on irrigation management. Farm labor hired for irrigating crops may not understand the soil, water, crop, and field relationships needed to achieve good efficiencies, or may not have the necessary experience. Use of irrigation scheduling services and other technical assistance relative to efficient operation of irrigation systems would aid most irrigators in making best use of the irrigation water supplies.

Institutional and Social Factors. — Onfarm irrigation effectiveness is influenced by existing laws and court decrees, as discussed under off-farm factors. An appropriator may use the total amount of water decreed, even if inefficiently, rather than lose the right to divert the water.

Irrigators may want better farm systems, but have to consider economic feasibility. The costs of improving an irrigation system will vary with the kinds of measures and degree of improvement, but current estimates range from $25 per acre for minor land leveling to more than $1,200 per acre for some sprinkler or drip irrigation systems. The resulting increase in net financial return is often inadequate to justify the cost of irrigation improvements.

Traditional agricultural practices affect use and management of irrigation water. Some examples of beneficial water application in addition to crop consumptive use are for seed germination, ease of harvesting, and environmental control.

The pricing policy of some utility companies has an effect on irrigation management practices. The annual "turn-on" fee charged by some utilities for irrigation pumping is large compared to the daily power cost. Therefore, once the power is turned on, the incentive for conservation is reduced because additional energy costs are relatively small.

Problems of environmental conflicts on the farm are similar to those on the conveyance and distribution system. The irrigator may be hesitant about or restricted from improving current irrigation systems. Policy of State and Federal agencies may prohibit technical and financial assistance for irrigation system improvement if negative impacts on environment are likely to result.

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[3] Summary Report, The Idaho Irrigation Survey, 1976.

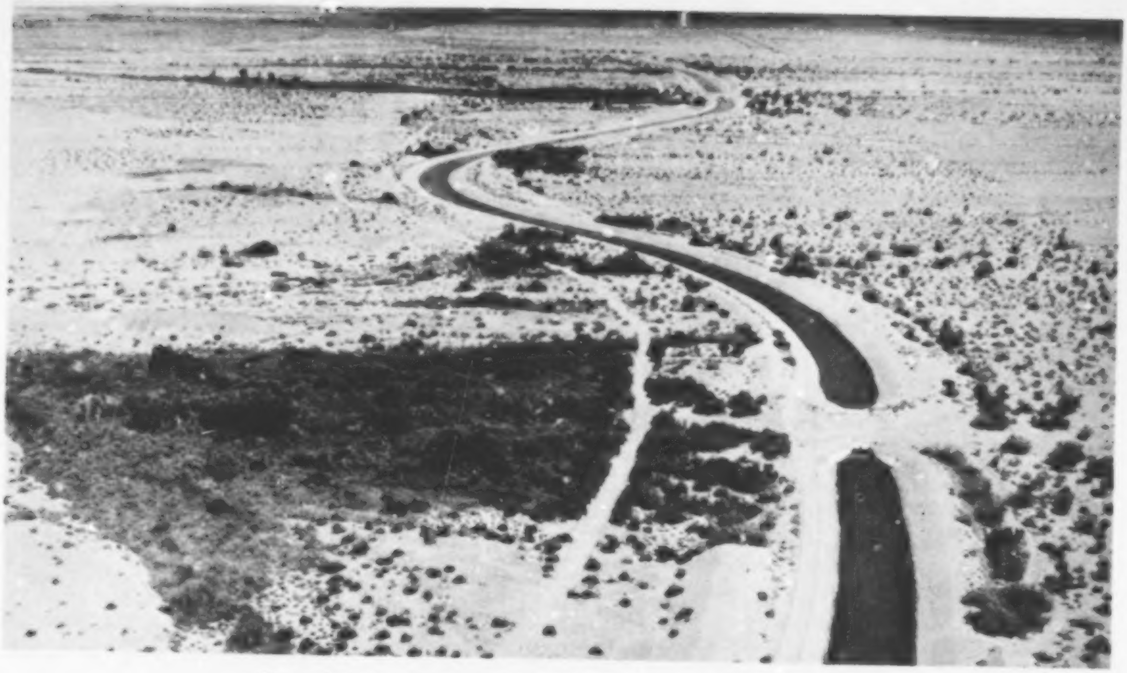


Figure 13.—Seepage from an unlined canal. (*Bureau of Reclamation photo.*)

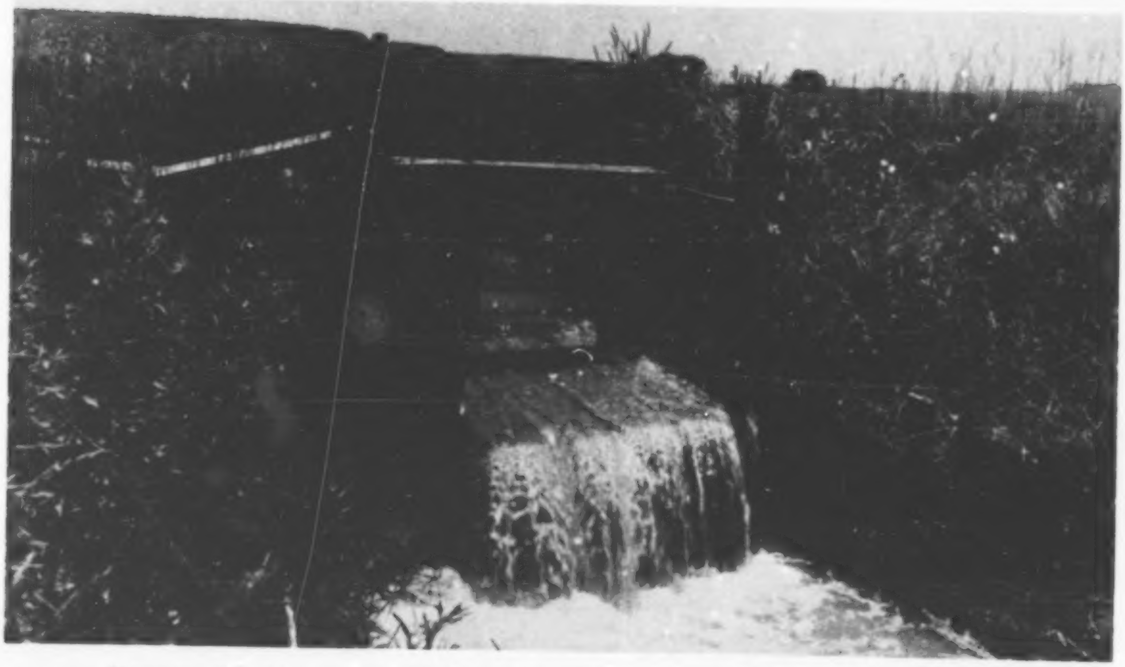


Figure 14.—Obsolete structures contribute to poor water management. (*Soil Conservation Service photo.*)

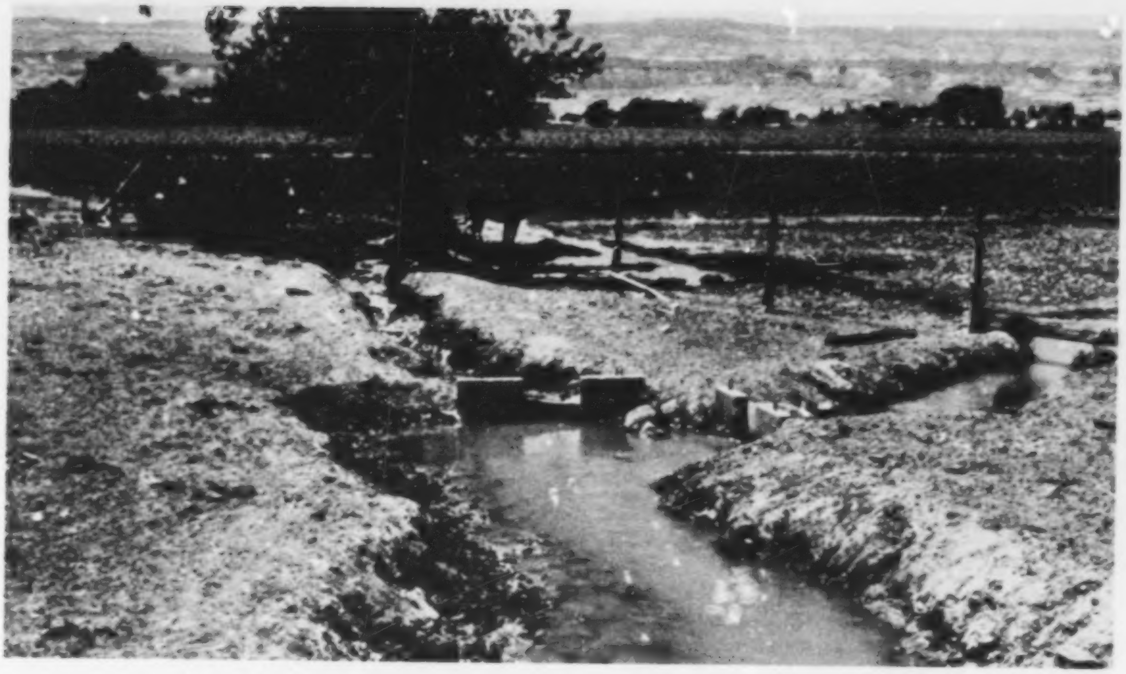


Figure 15.—Unlined, eroded farm ditch. (*Soil Conservation Service photo.*)

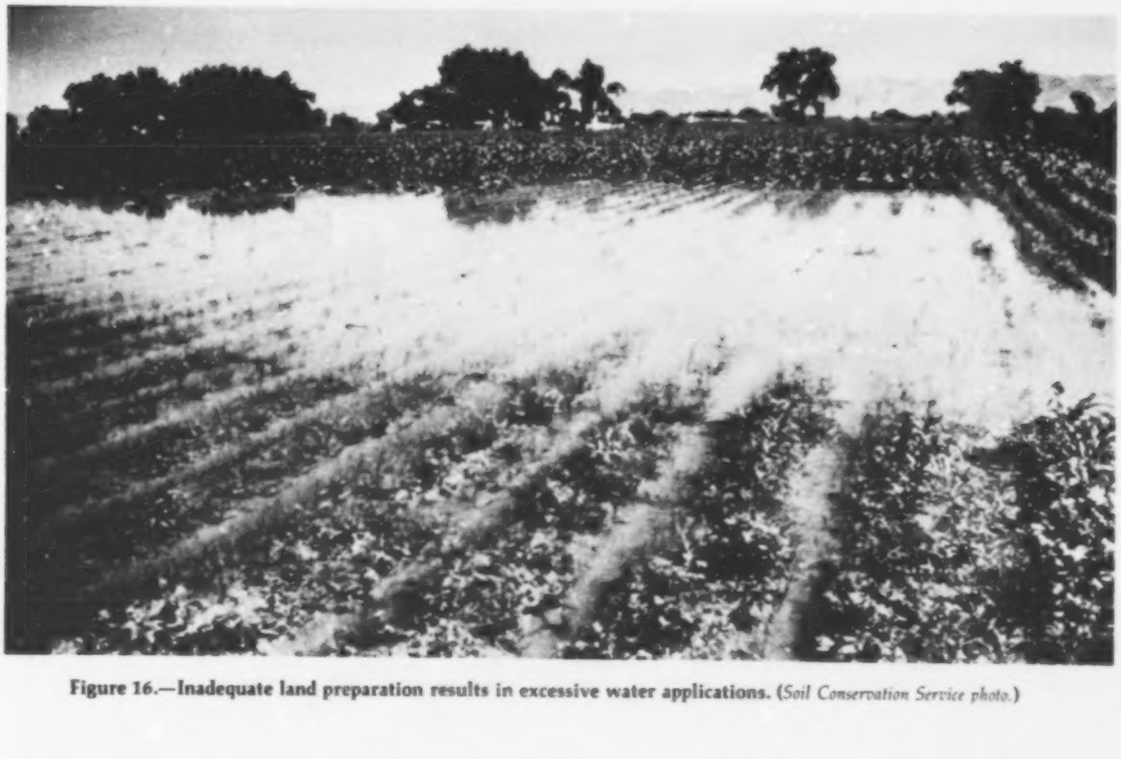


Figure 16.—Inadequate land preparation results in excessive water applications. (*Soil Conservation Service photo.*)

Results of Ineffective Use of Water

Some of the problems and impacts associated with irrigated agriculture are discussed in chapter 1. The following are specifically related to inefficient irrigation systems and practices.

The water consumed by evapotranspiration from an irrigated crop is only slightly affected by the method or efficiency of irrigation, as long as water availability to the crop roots is not limiting. Some of the problems resulting from ineffective use of irrigation water are caused by the volume and timing of irrigation water pumped or diverted, relative to crop needs. Large withdrawals on some streams leave remaining instream flows inadequate for aquatic life, recreation, and water quality maintenance between the point of diversion and the areas of return flow from the irrigation system. In other cases, irrigation works, particularly reservoir storage, improve seasonal flows when releases are made for downstream use during periods when streamflow otherwise would be inadequate to protect instream flow values.

When irrigation water is pumped from ground or surface water supplies, energy requirements are in direct proportion to the volume of water pumped. Thus, excess water applications increase energy use and require greater capacity of pumps, engines, and distribution conduits. In areas such as the Salt River Valley in Arizona and the Texas High Plains, where ground-water pumping exceeds the recharge rate of the aquifer, excess use of irrigation water decreases the useful life of the ground-water aquifer.

Ineffective irrigation water use and management often result in excess seepage and spillage from canals, deep percolation, surface runoff, and evaporation. These water "losses" can cause a variety of problems. Surface runoff often carries sediments eroded from irrigation fields or drainage channels. Nutrients or pesticides may be attached to the soil particles and also transported with the flow. The suspended sediment produces unfavorable conditions for aquatic life in the receiving rivers and reservoirs. Deposition in reservoirs decreases their capacity and useful life. The nutrients and pesticides may contribute to algae blooms and toxic conditions.

Natural infiltration and flows from seepage and deep percolation tend to pick up soluble minerals as they travel through the soil ground-water system. Deep percolating water may leach nitrates and other salts from the root zone as well. The geology of the irrigated area determines, along with the quantity and method of application, the degree of degradation of these waters. The ultimate destination of most pollutants is in deep aquifers or streams which intercept ground-water flows.

Seepage and deep percolation can cause excessively high water tables. These conditions may develop water-logged, seeped, and wetland areas on or adjacent to irrigated lands. This leads to additional incidental water use and loss of productive agricultural land. Seepage may reduce the amount of water delivered to farms. Inadequate deliveries make it difficult to irrigate the farms properly and may contribute to low onfarm irrigation efficiencies because of small or erratic flows. The resulting water shortages affect the economic base of irrigators. Irrigation districts may divert additional water to offset the effects of seepage.

Disparity between the pattern of seasonal water supply and crop needs is a rather consistent characteristic of many sections of the West. This disparity is an almost annual occurrence, particularly on those stream systems where little or no reservoir storage exists.

Such a condition is conducive to low irrigation efficiencies, principally during the period of high-water streamflow. With little or no control over the water supply, the irrigator seeks to optimize the situation by maintaining a saturated soil profile as far into the growing season as possible, while water is plentiful. Later, as streamflow subsides and the farmer spreads an ever-decreasing supply sparingly over a selected acreage of late-season crops, high efficiencies are generally achieved.

There are many variations of this condition, ranging from the extreme flow fluctuations which may exist in the higher parts of the stream system to those streamflow patterns in the lower reaches where return flows augment or stabilize late-season flows. The water deficit period is shown on figure 17.

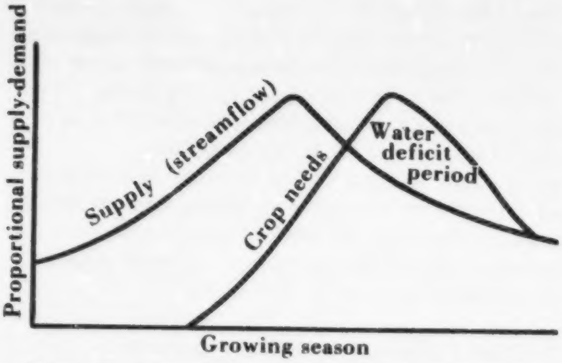


Figure 17.—General illustration of seasonal water supply compared to crop needs.

Inefficient irrigation can contribute to the loss of water for other uses in a river basin. Consumptive losses can result from incidental uses such as transpiration by phreatophytes fed by irrigation return flow or seepage, and from evaporation. Irrecoverable loss may result when percolating flow requires years or decades to reach a usable aquifer, or when water returned to the aquifer is of unsuitable quality or too deep for economic development. In a normal year the aggregate of such losses in the 17 western States is estimated at 13 percent of the irrigation diversion (figure 7). Measures to reduce these losses would make some of this water available for additional consumptive and instream uses within the upper basins and still provide for downstream uses and freshwater inflow to estuaries.

Problems of Data Collection

One of the primary problems in determining irrigation efficiencies is the inaccuracy of the data. First, there is the problem of accuracy in water measurement. The diversion measurement is compared to the measurements of farm deliveries to determine conveyance efficiency. The farm delivery measurements are on significantly smaller quantities of water than the total diversion to a conveyance facility. The comparison of these measurement points is subject to error. A reasonable accuracy of water measuring is plus or minus 5 to 10 percent, depending on the types of measuring devices being used.

Second, there is the problem of computing crop consumptive use. Lack of adequate climatic data makes it difficult to make good estimates of consumptive use using the current evapotranspiration formulas. However, the computation of crop consumptive use is probably more accurate than the measurement of water onto the field.

Decision-making data should be more accurate than those currently available on a wide basis. Data should be collected for a project or river basin area with specific attention directed toward determination of the accuracies of the irrigation water use. A determination should be made about what system improvements are really needed and the effectiveness of such improvements in reducing the diversion required to irrigate a crop.

Chapter 5
Measures, Costs, and Impacts

Since irrigation was first used to produce crops, man has been introducing ways of improving the transportation and application of water. Modern methods to improve irrigation efficiencies have evolved from years of experience and research. This chapter summarizes most of the measures needed to reduce the effects of the problems described in chapter 4; shows results of selected water conservation studies; presents some examples of specific measures and impacts; and describes probable costs and benefits.

Description of Measures

Improvement measures are available to treat both off-farm conveyance systems and onfarm problems. These measures can reduce inefficiencies that are caused by physical and management problems.

Off-farm System

The measures to treat off-farm problems are related to the physical and management aspects of conveying water from a point of supply (diversion or reservoir) to the individual irrigators. Additional labor can contribute to increased efficiency by providing better service to the irrigator. These measures are not applicable in the irrigation situation where the water used is pumped from water supplies on the farm.

Physical measures consist of the construction of conveyance and distribution linings, installation of closed pipe systems, and the consolidation and/or realignment of systems. In addition, the replacement or installation of regulation structures, proper maintenance, and control of aquatic and/or ditchbank weeds are considered physical measures. Examples of measures for the improvement of conveyance systems are shown on figure 18.

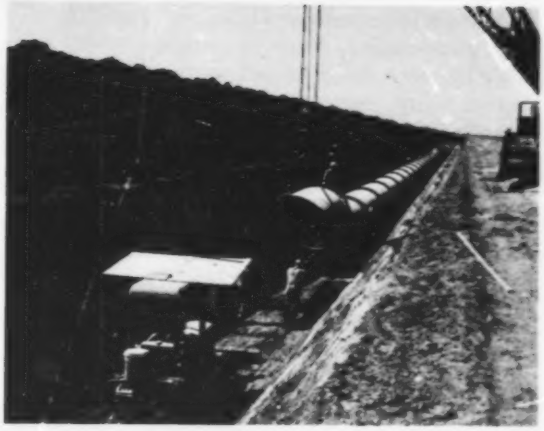
Linings will reduce seepage from canals and laterals and effectively improve water distribution and management. Linings consist of impervious material installed within the perimeter of a waterway.

Linings can be either exposed to the atmosphere, such as concrete linings, or buried beneath a cover material, such as plastic linings. They can consist of compacted earth materials, hard-surfaced materials such as concrete or soil cement, or membranes such as asphalt and flexible plastic. The selection of the material is generally based on its availability and cost and the geographic location or climate where it is intended to be used. Each type of material has distinct advantages and disadvantages.

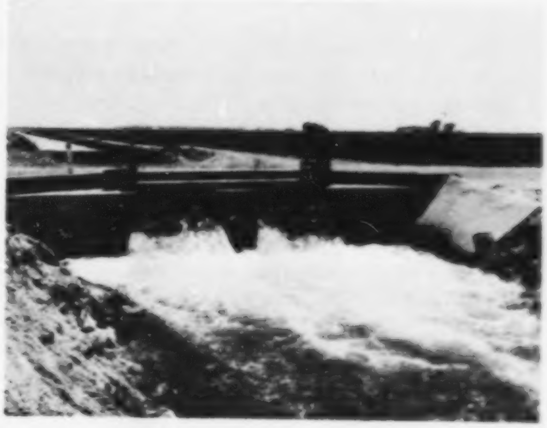
Entire conveyance systems have been lined in this country in the past, resulting in very significant improvements in conveyance efficiencies on such systems. A comparison can be made between the expected seepage rates of various lining materials. For example, a compacted earth lining of silty clay has an expected seepage rate of about 0.32 cubic feet per square foot of wetted perimeter per day ($ft^3/ft^2/day$), while concrete lining has a rate of about 0.08 $ft^3/ft^2/day$.

There are other benefits to lining systems in addition to reducing seepage. They include (1) the control of ditchbank weeds and aquatic growth which consumes water and requires use of herbicides, (2) a reduction of soil erosion, (3) an improvement in water quality, (4) a reduction in operation and maintenance costs, (5) reduced drainage requirements, and (6) reclamation of agricultural lands lost to seepage. There also may be detrimental effects of lining

Concrete lined canal. (*Bureau of Reclamation photo.*)



Installation of large pipelines in lieu of open ditch. (*Bureau of Reclamation photo.*)



Canal control structure. (*Bureau of Reclamation photo.*)

Figure 18.—Selected measures — conveyance systems.

waterways, such as (1) a reduction in vegetation and open water used by wildlife, (2) a physical hazard to mammals, and (3) less percolation to ground water.

Piped conveyance systems are an effective means of improving irrigation operations and water use. They provide a means of completely enclosing a system to avoid many of the physical losses of water occurring in an open system. In the past, pipelines to carry irrigation water were used mainly where physical barriers such as steep escarpments and canyons made open systems impractical. Planners today usually consider piping conveyance and distribution systems in the early planning stages. In mountain valley situations, consideration should be given to installing pipelines for gravity sprinkler systems.

Relatively few piped systems have been installed to date. Where piped systems have been installed, conveyance and distribution efficiencies greater than 95 percent have been attained. Impacts of piped systems other than water conservation are very similar to those listed above for system lining. Additional benefits include better utilization of lands along system rights-of-way, elimination of safety hazards common to open systems, reduction of evaporation losses, and better control of water delivered to the farm, thus providing more options for the farmer.

Many conveyance systems were constructed along the contours of the land to minimize excavation and fill construction activities which in the past were performed by crude and inefficient machinery. This resulted in the existence of many long and winding systems which have very high losses. Piping of such systems increases the off-farm conveyance efficiency, reduces seepage, and reduces operation and maintenance costs.

Consolidation and/or realignment is possible today because of modern construction methods. Better irrigation system features such as improved water control structures and lining and piping materials also make consolidation and/or realignment practical as effective water conservation measures. Benefits include (1) reduced operation and maintenance activities for water users, (2) improved farm unit layout, (3) elimination of weeds along deleted waterways, (4) improved service to water users, (5) improved economic use of the land, and (6) reduction of diversion requirement. Some detrimental effects of consolidation and/or realignment include a reduction in vegetation utilized by wildlife and a reduced recharge of ground water.

Water measurement accuracy is important in the operation of any water conveyance system. Even though a surplus of water may exist on an irrigation project, measuring devices are essential if an accurate accounting of what happens to the water is to be made. Proper evaluation of losses is necessary to establish the economic advisability of providing canal linings.

Inline structures include water measurement and regulating structures. Regulating devices are checks, check-drops, turnouts, diversion structures, check inlets, control inlets, and regulating reservoirs. These structures are used to regulate the flow passing through the conveyance system and/or control the elevation of the upstream water surface. The equitable delivery of water to irrigators is dependent upon the size of the discharge openings, referred to as farm turnouts, and the water level behind the openings. If the structures of the system cannot maintain a constant or uniform water level, proper deliveries cannot be made to the irrigator. This may cause irrigators to use the water supply inefficiently. The use of proper check structures in a system also regulates the water level along the system, thus reducing operational wastes and losses.

The *automation of regulating structures* is designed to increase the overall efficiency of the system and reduce operational waste. While storage reservoirs and the outlet works of dams, diversion dams and canal headworks are often self-contained and isolated, they can be the focal point for demands of the conveyance system. The proper operation of these facilities through automation can help meet downstream diversion demands in the river (water rights and/or fish and wildlife commitments), and also lessen hydraulic fluctuations to provide smooth operation of the entire system. Automatic controls of check structures can sense deviations of water surfaces on the canal and operate adjacent checks upstream and downstream to provide a nearly constant water level. Automation of turnouts provides uniform deliveries from the distribution system to the farm. Wasteways are the traditional safety valves of the canal operation. They remove excess water and prevent overtopping of the canal. Operational wastes can be eliminated or greatly reduced when a high degree of automation is utilized on other structures within the system.

Benefits that would accrue as a result of automation of facilities would be both tangible and intangible. The tangible benefits could be reduced operation and maintenance costs of the conveyance and distribution system. Intangible benefits might include a more reliable water supply, safety, and aesthetic values. A recent study by the Water Conservation Opportunities study team indicated that on 61 projects constructed by the Department of the Interior, a 7 percent reduction in diversion could be accomplished through automation and improved control facilities.[1] These 61 projects were considered to have the highest potential for water conservation.

Proper *maintenance of facilities* that control and regulate the flow of water is fundamental to good water management practices of the project and the water users. The accuracy of measuring devices, most important for efficient operations, can be assured through inspection and routine maintenance. Facilities designed to maintain water levels in the system need to be under a regular maintenance program to provide optimum service. The regular removal of debris from the system throughout the season and removal of sediment during the off-season will eliminate many operating problems.

A *weed control program* can effectively minimize excessive vegetation in and along ditchbanks and can be accomplished by mechanical, chemical, or biological means. Any method of control will have economic and environmental impacts. Chemical control is generally the most effective and economical but may not be environmentally acceptable. Mechanical control is less effective and more costly in manpower and equipment. Benefits of a routine weed control program will be increased water delivery capacity, reduced operation and maintenance costs, and reduced water consumption by ditchbank vegetation.

Conveyance design. — The application of any measure which may improve onfarm efficiency is often limited by the design and management of the conveyance and distribution system. Existing systems have been designed to deliver water by a continuous flow, rotation, or demand method. The continuous flow and rotation methods may discourage efficient onfarm and system water use. The rotation delivery system is designed with a capacity to deliver water for short periods of time at scheduled regular intervals. The demand system of delivery is designed with a capacity to deliver on short notice the flow ordered by an irrigator. The demand method is best suited to promote the efficient use of water. Any improvement measures, either onfarm or in the system, should be interrelated with the delivery capacities of the system. This will provide the type of irrigation delivery system which will allow the irrigator flexibility in choosing onfarm methods to conserve water. However, to change from one method to a more efficient method may require installation of costly structural measures.

Scheduling water deliveries is an important water management measure. The Bureau of Reclamation Irrigation Management Services program provides for the compilation and organization of water delivery schedules for the farms on the conveyance system. Scheduling deliveries provides for the allocation of water in accordance with actual and projected crop use, rainfall, cultural practices, delivery system carrying capacify, and field irrigation characteristics. Deliveries can be scheduled to make the most effective and efficient use of the total water supply. Use of scheduling might eliminate the need for enlargement of the conveyance system to deliver more efficient flows. Scheduling deliveries on most distribution systems can be accomplished without additional operating personnel.

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[1] Report on the "Water Conservation Opportunities" study, carried out by the Bureau of Reclamation and the Bureau of Indian Affairs, September 1978.

Onfarm

The onfarm measures are those that affect the problems causing inefficiency on the farm. These measures deal with the onfarm delivery system, field application system, and water management problems. Each measure has some degree of effectiveness in each irrigation situation. Figure 19 shows examples of good onfarm measures.

Ditch lining or piping. — An effective method of reducing seepage is to line ditches with concrete, asphalt, or other impervious material, or replace them with pipelines. These measures are similar to lining or piping off-farm systems. Ditch lining may be less costly to install but is not suitable to all topography and farm layouts. Piping is more effective than ditch lining in managing water because it eliminates evaporation and when buried can be farmed over and automated easily. Both lining and piping would reduce labor and maintenance costs of the irrigator.

Land leveling is reshaping the surface of a field to planned irrigation grades or slopes and is most important in surface systems. Proper land grades for the field application system being used allow better control and more uniform application of water, which may result in increased efficiency.

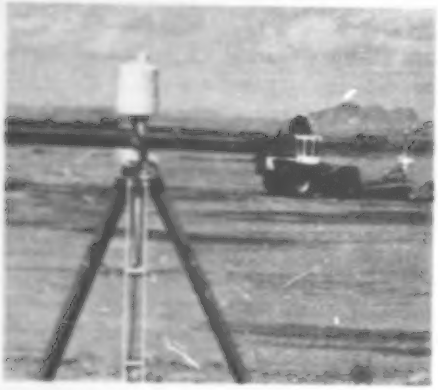
Water control structures are those onfarm facilities that control and regulate the flow of water from the farm delivery point to the field. These facilities are similar to the off-farm inline structures, but are designed for smaller flows. Examples of water control and regulating structures are checks, drops, divider boxes, and reservoirs. The control and regulation of waterflow on the farm is required to distribute water throughout the onfarm delivery system. Using divider boxes and checks, water can be diverted from one location to another. Checks are used to maintain the constant water level required to achieve efficient application of water on the fields. Drop structures allow the transportation of water along steep slopes, while maintaining a nonerosive slope in each reach of the conveyance system. Onfarm reservoirs can accumulate low flow rates from wells or canals until a sufficient volume is available for efficient application. Water control structures are most effective in the mountain meadow and intermediate valley irrigation situations where the onfarm delivery systems are relatively old and usually lacking in measuring devices and structures.

An *automated irrigation system* is a farm delivery system equipped with gates and/or valves which are controlled by a sequencing timer alone or a sequencing timer with soil moisture sensors. The primary purposes for use of automated systems are to reduce the irrigation labor requirement and provide the means to improve efficiency. A properly installed and maintained system will result in better water management. Lined ditch or pipeline systems can be automated. Equipment is available for large ditch systems but is expensive.

Flow measurement devices. — For the irrigator to apply the specified amount of water at each irrigation, he must have some method of water measurement. Flow measurement devices can be installed in open ditches and in pipelines. Some examples are Parshall flumes, cutthroat flumes, weirs, orifice plates, and flow meters. Installation of these devices alone will not conserve water. As with the devices used in the off-farm systems, they must be maintained and used by the irrigator to be effective.

Tailwater recovery systems are used to catch runoff created by irrigation and return the water into the original delivery system or onto another irrigated field. The system usually consists of a sump, pit, or collection reservoir located below the irrigated area, a pump, and a pipeline to deliver water back to the delivery system or to the irrigated field.

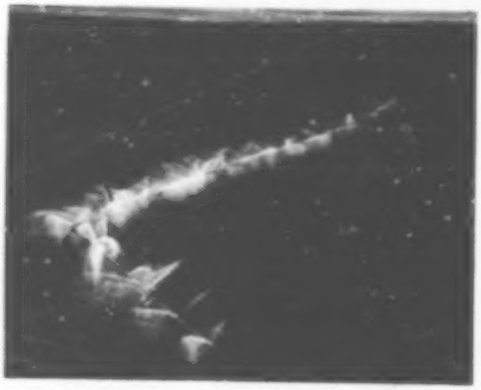
Selection of application method. — Three methods of irrigation water application — surface, sprinkler, and drip — were described in chapter 1. Switching from one of these methods to another constitutes a change in method of irrigation water application. This is a valid alternative for improving water use and management where the existing irrigation system is poorly suited to the site conditions and the desired degree of efficiency cannot be obtained by improving the system design.



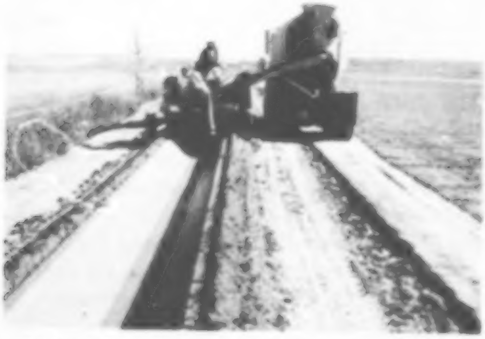
Land leveling by laser beam control. (*Bureau of Reclamation photo.*)

Turnout for flood irrigation. (*Soil Conservation Service photo.*)

Gated pipe installation. (*Soil Conservation Service photo.*)



Onfarm measures — center-pivot sprinklers. (*Valmont Industries photo.*)



Lining a farm ditch. (*Soil Conservation Service photo.*)

Figure 19.—Onfarm measures.

No one irrigation method is consistently more efficient than other methods, and conversion from one method to another should not be based on such a premise. The potential change in method should be based on evaluation of land slope, crops to be irrigated, water supply, water intake and holding capacity of the soil, labor, and other factors, including economic and environmental impacts. The method selected should conserve soil as well as water. To do this, it may be necessary or desirable to use more than one method of irrigation on any given farm.

A change from surface to sprinkler irrigation may be warranted when soils have high intake rates that cause excessive deep percolation with surface methods; fields are steep or have complex slopes; or light, frequent water applications are required due to crop requirements or soil water-holding characteristics. Efficient surface irrigation is possible, except on steep slopes and coarse-textured soils, when flow rates, time of set, and length of run are properly chosen. Surface systems may be preferred when large water applications are needed for leaching to maintain salt balance; when sprinkling with low quality water would cause damage to crop foliage; when effective use of rainfall and erosion control is feasible by land leveling; or when sprinkler evaporation losses are excessive due to wind and other climatic conditions. Drip irrigation should be considered when (1) the water supply is limited, (2) there is need for a high degree of automation (reduced labor), (3) slopes are excessive, or (4) the cost of water is high.

Improved application method. — The improved design of an existing application method can be effective in managing irrigation water by facilitating better control of the available water supply. Other purposes may include more effective use of rainfall and labor, reduction of energy requirements, reduction in operation and maintenance costs, and provision for safety features. Reorganization of irrigation systems should be based on analyses of the particular site conditions by personnel who have expertise in irrigation design and water management.

Examples of design changes for sprinkler systems include reorificing sprinkler heads, and changing sprinkler spacings and operating pressures to improve distribution patterns and application rates. Surface system design may often be improved by adjusting run lengths and furrow streams to prevent excessive deep percolation and runoff; changing dimensions of border strips to obtain proper advance and recession of the irrigation streams; reducing irrigation grades by land leveling; adjusting spacing of field ditches; and adding tailwater recovery facilities, automation, and measuring equipment.

Onfarm irrigation water management is the determination and control of the rate, amount, and timing of irrigation water application to soils to supply water needs in a planned and efficient manner. Improvements in water management can reduce mining of ground water supplies, reduce diversion rates from natural streams or reservoirs, reduce tailwater runoff, reduce deep percolation losses, reduce nutrient losses, improve water quality, and improve crop yields. Management improvements can be made by irrigation scheduling and applying water in desired rates and amounts. Many irrigators apply water on a set schedule without regard to the crop needs or moisture-holding capabilities of the soil because of habit or other constraints. Inadequate or ill-timed applications can result in lowered crop yields. Irrigation scheduling involves use of data on soil moisture availability, crop water requirements, and rainfall to achieve a soil moisture balance for the irrigator's fields. Additional labor can often allow the irrigator to better manage his water.

The Bureau of Reclamation provides an Irrigation Management Services (IMS) program to districts associated with Reclamation projects. Several universities, State agencies, irrigation organizations, and numerous private firms provide similar services in specific locations throughout the western States. In 1977, the Bureau of Reclamation assisted in providing field irrigation scheduling through cooperative agreements to about 157,000 acres on Federal projects. These agreements are for the purpose of training irrigation organization personnel during a demonstration and development period. Following this period, it is expected that the irrigation organization will continue the service to their water users. Also in 1977, a survey of 11 private firms indicated that these firms provided similar services to about 570,000 acres.

Scheduling is most effective when irrigation water supplies are adequate, but can be useful in managing a limited supply. If a complete scheduling program is not used, soil moisture determination by itself can improve water management. Whether the determination is made by a shovel, probe, moisture block, or tensiometer, the level of soil moisture is estimated and irrigation water is applied if moisture is below a specified level. This specified level will vary depending on the soil, climate, crop, and stage of crop development. Excess water application may cause surface runoff or deep percolation. Inadequate application will not maintain an optimum moisture level and will require more frequent irrigations. The timing and measurement of water are essential to determine how much is being applied.

The reduction in irrigation water use in central Nebraska because of improved irrigation water scheduling is an example of the potential benefits of irrigation scheduling programs. On those lands on which irrigation scheduling was used in central Nebraska in 1976, the amount of water applied was reduced from 25 to 15 inches. The 9-inch reduction in water withdrawals by irrigators who scheduled versus irrigators who did not schedule resulted in a 38 percent savings of energy used to pump the water.[2] The University of Nebraska irrigation scheduling technique used a computerized scheduling program on Nebraska's AGNET computer system. Data for the AGNET program were collected from electrical resistance blocks placed in the soil within the root zone at depths of .5, 1.5, 2.5, and 3.5 feet. Irrigations were scheduled when the moisture in the root zone was more than 50 percent depleted. The irrigation water applied was less than that necessary to fill the soil profile completely, so the soil could absorb rainfall if it should occur.

The onsite effects of irrigation scheduling in this case were definitely beneficial in that water withdrawal was reduced, thus conserving energy. The impacts of scheduling on crop yields were not presented in this paper; however, yields usually remain about the same. The offsite impacts related to reduced runoff and erosion, reduced deep percolation, and possible changes in both ground and surface water quality were not measured. These offsite impacts will become more readily visible as additional irrigators adopt scheduling techniques. These techniques are difficult to implement where irrigators are subject to cuts or interruptions in electric power.

The Bureau of Reclamation cooperates with the Soil Conservation Service, Cooperative Extension Service, and National Weather Service in conducting its IMS program. Most of this cooperative effort is directed toward providing farmers with crop consumptive use information. Additional coordination with these agencies could enhance the IMS program. A single example of additional coordination is demonstrated in the Wellton-Mohawk Irrigation and Drainage District. In that district the IMS program provides irrigation scheduling while the Soil Conservation Service and Cooperative Extension Service have worked closely with the farmers to improve the onfarm systems and advise the farmers on how to apply the water more efficiently and uniformly. To make the cooperative effort work, the agencies need to put priorities on the program and have personnel and budget to assist. The Bureau of Reclamation has signed contracts on several Federal projects for developing local IMS programs. The Soil Conservation Service and Extension Service could provide additional assistance and also enhance the opportunity of expanding the program to non-Federal project water users. Training people in the use of Irrigation Management Services will broaden the program in each area. The cooperating agencies could also search different areas for implementing the program and jointly determine where the greatest accomplishment could occur.

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[2] "Scheduling Irrigations Helps Conserve Water and Energy," by Paul E. Fischbach and Thomas Thompson, Nebraska Irrigation Shortcourse, Agricultural Engineering Department, University of Nebraska-Lincoln, January 1978.

Institutional and Social Measures

Institutional and social measures may include such things as research, education, demonstration projects, legislative action, or better coordination between interested parties. These measures may affect implementation of treatment measures to improve irrigation water use and management. Table 10 summarizes some of these measures. Approaches to implementing these types of measures will be discussed later in this chapter.

Combinations of Measures

Combinations of off-farm and onfarm measures can be designed to provide the best overall water management. An example of an irrigation system designed to improve both off-farm and onfarm water use is the gravity pressured sprinkler systems in the Star Valley area of Wyoming.[3] Water had previously been diverted from streams through canals with considerable conveyance loss. The water was then distributed on the field using flood irrigation techniques on most farms. The new systems use structures on the streams which divert water from the upper level of the stream into pipelines for delivery under gravity pressure to individual irrigators. The irrigators have installed sprinkler irrigation systems.

These gravity pipelines were installed during 1971-75 at a cost of nearly $300 per acre. The new system improved conveyance efficiency from about 60 percent to nearly 100 percent, and improved farm irrigation efficiency from approximately 15 percent to about 65 percent. This improvement in overall irrigation delivery and field efficiency resulted in a considerable reduction in stream withdrawal requirements. The streamflow can now provide a full supply of irrigation water 96 percent of the time. At the same time, a minimum flow of 6.4 cubic feet per second can now be maintained in Cottonwood Creek below the diversion, allowing some water to flow through 4 miles of channel that was previously dry part of the year.

Some improvements in water quality due to the reduction in erosion and in leaching of crop nutrients from fields have been observed. Instream flow conditions have improved due to reduced diversions.

The major benefits accruing from the irrigation system conversion are in the form of increased agricultural production. Some irrigators in the Star Valley area have experienced more than a doubling of previous hay and grain yields. This increase in yields is likely due to better distribution of water on the field and to improved application and use of late-season water because of the reduction in off-farm and onfarm seepage and return flows.

This type of irrigation system conversion appears to have considerable merit in the high mountain valley areas where gravity pipeline systems may be able to supply adequate pressure to operate sprinkler irrigation systems or other relatively efficient irrigation systems without the use of energy. However, it should be noted that improved systems may increase the crop consumptive use of water, particularly in the late season when streamflows previously had been inadequate to meet total irrigation needs. The impact of this increased consumptive use of water on downstream users will depend upon the present water allocation, and on the overall impact of the irrigation system conversion on streamflows due both to the increased crop consumptive use and the change in both ground and surface water seasonal flows. Thus, gravity pipelines with sprinkler irrigation systems must be carefully evaluated for each site, not only from the standpoint of economic, social, and environmental impacts on the immediate area, but also on the economic and environmental impacts which may occur downstream or on ground-water aquifers.

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[3] References: (1) Watershed Work Plan, Cottonwood Creek Watershed, Lincoln County, Wyoming. Prepared by the Star Valley Soil and Water Conservation District, April 1967; (2) Watershed Work Plan, Star Valley-Dry Creek, Lincoln County, Wyoming. Prepared by the Dry Creek Irrigation Company and Star Valley Soil and Water Conservation District, June 1966; and (3) Western Wyoming Resource Conservation and Development Project, West Afton Sprinkler Farm Irrigation Measure Plan, Measure No. 156. Sponsored by the West Afton Sprinkler Company and Star Valley Conservation District, Lincoln County, Wyoming. December 1974 and revised April 1976.

Table 10.—*Institutional, economical, and social factors and measures affecting implementation.*

Factors	Measures
Existing water laws or court decrees (compacts)	
Examples: Water conserved may not be available to saver. "Use it or lose it" policies. Deliveries not based on beneficial use.	Incentives for improving irrigation efficiencies Better definition of beneficial use as related to crop consumptive use and efficiencies or more detailed procedure for administration. Laws to control intermingling of surface and ground-water supplies.
Environmental conflicts	
Examples: Restrictions in technical or financial assistance on measures causing adverse impacts. Reduction or damage in wetland wildlife habitat. Concrete lining may be hazardous to terrestrial wildlife. Restricted use of toxic materials.	Better coordination between water resources and environmental groups. Re-evaluation of process for determining mitigation costs. Better management of remaining wildlife habitat.
Financial capabilities	
Examples: Limitations on cost-sharing programs. Cost of energy (effect on method of application).	Cost-sharing programs tied to water management achievements. Non-reimbursable costs of some water conservation measures. Special cost-sharing programs for areawide measures.
Insufficient technical assistance	Additional trained personnel. Training incentives.
Social	
Examples: Changes in land use tradition. Public support and involvement poor or lacking. Lack of skilled irrigators. Tradition.	Coordination of land use legislation and water supply. Increased public awareness. Special demonstration projects. Research. Education.

Effectiveness of Measures

As a means of determining the suitability of the measures described in this chapter, the work group evaluated their effectiveness in solving the problems described in chapter 4.[4] Table 11 summarizes the improvement measures that relate to each problem. Because of the complexities of interrelated problems at a particular location, the measures could not be ranked or scored against each other. Each measure was judged on its own merit within each irrigation situation for short- and long-term effectiveness. Short-term effectiveness was considered to be the benefits that could be expected within about a 10-year period. Where the implementation of the measure was expected to require more than 10 years, the long-term effectiveness was classified higher. As an example, the use of canal and lateral lining to reduce seepage in the intermediate valley situation was determined least effective in the short term, but highly effective in the long term. The factors for determining

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[4] Procedure adopted from the "Water Conservation Opportunities" study, Department of the Interior, Bureau of Reclamation and Bureau of Indian Affairs, September 1978.

Table 11.—*Measures to improve irrigation water use and management.*

Problems	Measures	Effectiveness of measures within each situation[1], [2]							
		Short term				Long term			
		Mountain Meadows	Intermediate Valleys	On-Farm Supply	Lower Valleys	Mountain Meadows	Intermediate Valleys	On-Farm Supply	Lower Valleys
	OFF-FARM								
Physical									
Seepage and vegetative growth	Canal and lateral lining	L	L	NA	M	L	H	NA	H
	Replacement of open canals and laterals with closed pipe	M	L		L	M	H		M
	Consolidation and/or realignment of the conveyance and distribution systems	M	L		L	H	H		L
Obsolete, inadequate, or improperly maintained facilities	Control of aquatic and/or ditchbank weeds	M	H		H	M	H		H
	Replacement or installation of facilities	H	H		L	H	H		L
	Examples: flow measuring devices in-line structures alteration of delivery capacities installation of automation equipment								
	Proper maintenance of facilities	H	H		L	H	H		L
Management									
Poor management of the system	Change in operating policy by irrigation district	L	M		L	L	M		M
	Example: delivery on demand instead of continuous flow or rotation								
	Scheduling and coordination of water deliveries	L	H	↓	H	L	H	↓	H
	ONFARM								
Physical									
Delivery system	Tailwater recovery system	L	L	H	L	L	L	L	L
	Flow measurement devices	M	H	H	M	M	H	H	M
	Ditch lining or piping	M	M	H	M	H	M	H	M
	Installation of automation equipment	M	L	M	L	M	L	M	M
	Water control structures	M	H	L	L	M	H	L	L
Field application system	Land leveling	L	M	M	H	M	M	M	H
	Improved design of application method	M	H	H	H	H	H	H	H
	Change in method (i.e. switch to level basin sprinkler, or trickle where soils, topography and crop are suitable)								
Management									
Poor onfarm water management	Irrigation water management	H	H	H	H	H	H	H	H
	Examples: irrigation scheduling water measurements								

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[1] See chapter 1 for description of irrigation situations.

[2] Each measure was judged on its own merit within each irrigation situation.

NA — Not Applicable
L — Least effective
M — Moderately effective
H — Highly effective

the short- and long-term effectiveness of measures were:

1. *Planning, design, and construction time required.* — Measures afforded time for planning, design, and construction would have a higher effectiveness in the long term.

2. *Existing programs.* — Measures that could be implemented through existing programs were determined to have a higher effectiveness in the short term if not constrained by other factors. These measures would have a similar effectiveness in the long term if constraining factors were removed.

3. *Water rights.* — Measures were determined to have a lower effectiveness in the short term if constrained by existing water rights and laws.

4. *Availability of educational and technical assistance.* — Some measures will have a lower effectiveness if short-term technical assistance is not available or time is required to train personnel.

Effectiveness of the measures was termed as highly effective (H), moderately effective (M), least effective (L), and not applicable (NA). The following factors were considered in judging each measure:

1. Economics (probable cost versus potential benefits).
2. State-of-the-art.
3. Acceptability (social).
4. Variations in irrigated areas.
5. Severity of associated problems in each irrigation situation.

The effectiveness of any one measure or group of measures to improve water use and management is dependent upon existing conditions.

Results of Studies

Two recent efforts have been undertaken to evaluate the opportunity to achieve water conservation in irrigated areas in the West. One study was carried out by the Soil Conservation Service for all irrigated land in the 17 western States. The Bureau of Reclamation and the Bureau of Indian Affairs have reviewed water conservation opportunities in 61 selected Federal projects.[5]

Soil Conservation Service Study

The Soil Conservation Service made field estimates of needed measures to achieve a reasonable level of irrigation water management. These are shown in table 12 for both off-farm conveyance systems and onfarm systems for the 17 western States. The improvement most needed to reduce seepage losses from canals and laterals is lining or piping. Over 30,000 miles of canals and laterals are in such condition that lining or replacement with pipe would be needed to reduce seepage, evaporation, and phreatophyte consumption to a reasonable level. Consolidation, realignment, or enlargement of 8,000 miles of canals is needed also, along with 93,300 water control structures, to provide conveyance systems which can be managed efficiently with minimum operational spillage.

Table 12. — *Measures needed for improved irrigation water management — 17 western States.*

Off-farm conveyance systems	
Consolidation, realignment and enlargement	8,000 miles
Lining and piping	30,300 miles
Control structures	93,300 each
Onfarm	
Lining and piping	90,500 miles
Land leveling	11,620,000 acres
Control structures	5,470,000 each
Change in method	3,520,000 acres
Tailwater recovery systems	15,750,000 acres
Irrigation water management	28,420,000 acres
Automation	20,640,000 acres

Onfarm measures most often needed are lining or piping of field distribution systems, land leveling, water control or measuring structures, and automation. Other important measures include tailwater recovery systems and changes to pressurized systems (sprinkler and drip). About one-fourth of the irrigated land in surface systems requires land leveling, over one-third could use tailwater recovery systems to reduce return flows, and about 60 percent should use more effective ways to schedule and apply water to meet the needs of the crops and reduce deep percolation and excessive return flow.

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[5] Report on the "Water Conservation Opportunities" study carried out by the Bureau of Reclamation and the Bureau of Indian Affairs, September 1978.

Water Conservation Opportunities Study

In the study carried out by the Bureau of Reclamation and Bureau of Indian Affairs, Department of the Interior, the average system efficiency of the 61 projects was an estimated 44 percent; and in over one-third, the present efficiency is less than 30 percent. Water conservation measures shown in table 13, if implemented, would raise the overall efficiency to an estimated 61 percent. About two-thirds of this improvement would result from better management and improvement in the conveyance systems. The remaining improvement would result from onfarm measures. The relative effectiveness of the various types of measures can be determined by comparing the reduction in diverted water as shown in the table. Seepage reduction of lining or piping canals, laterals, and ditches accounts for over half of the reduced diversions. The term "water conservation" used in the Interior study does not imply that all of the reduced diversions would be available for additional beneficial uses. The potential reduction in diversions is used as only one indicator of the potential for conserving water. However, of the 3.1 million acre-feet reduced diversion potential identified, approximately 2.4 million acre-feet are now being used by others as return flow.

Table 13. — *Water conservation measures for 61 projects. Total irrigated area — 2,370,608 acres*

Type of Conservation Measure	Reduction in Diversions (acre-feet)
Off-farm conveyance systems	
Improved water management	311,520
Seepage reduction	1,144,485
Automatic and control measures	221,775
Return flow	343,325
Other	59,000
Subtotal	2,055,105
Onfarm	
Seepage reduction	398,723
Level-reorient fields	110,972
Irrigation scheduling	187,834
Improved application methods	233,063
Recycle irrigation runoff	102,275
Subtotal	1,032,867
Total	3,087,972

Water Budgets — 17 Western States

Using the Soil Conservation Service study data (1975), water budgets (table 14) were prepared for the six characterization areas in the 17 western States. These budgets were developed for a normal precipitation year (precipitation amount is equaled or exceeded 50 years out of 100).

If all the measures in the Soil Conservation Service survey were implemented under a 25-year accelerated program, it is estimated that conveyance efficiency could be increased 10 percent, and onfarm efficiencies 13 percent. In the 17 western States, with no increase in irrigated acreage and providing water to water-short areas, return flows could be reduced by 35.3 million acre-feet and net depletion by 3.3 million acre-feet. This results in a reduction in diversions of 38.6 million acre-feet. The **only** water that could be available for other consumptive use is the 3.3 million acre-feet. Reductions in return flows and diversions make **no** water available for reallocation, but could make some water available for enhancement of instream flows in some reaches. In four of the characterized areas, the SCS study indicated that net depletion could increase if a full water supply to water-short irrigated areas resulted from implementation of the water conservation measures.

The continuation of the ongoing programs (trend) as described in chapter 3, with no increase in acreage and a full water supply, should result in (1) an increase in conveyance efficiency of 4 percent, (2) an increase in onfarm efficiency of 6 percent, (3) reduction in return flows by 13.9 million acre-feet, and (4) a reduction in diversion of 12.7 million acre-feet.

Table 14.--*Water budgets by characterization areas, 17 western States, based on a normal precipitation year — for present situation and two alternative situations in year 2000.* (Based on Second National Water Assessment.)

Area	Irrigated acreage	Gross diversion	Farm delivery	Crop requirement	Incidental use	Net depletion	Return flow	Conveyance efficiency	Onfarm efficiency
	(1,000 acres)	*(- - - - - -*			*million acre-feet*		*- - - - - -)*	*(- - - - -*	*percent - - - - -)*
Present — (1975 base) with 4.3 million acre-feet shortage in meeting crop requirement									
Northwest	5,513	33.3	20.4	8.1	2.9	11.0	22.3	61	40
Southwest	11,216	50.2	41.9	25.7	8.0	33.7	16.5	83	61
Intermountain	2,042	7.5	6.2	2.7	0.9	3.6	3.9	83	44
Rocky Mountain	4,010	17.7	10.9	4.4	1.6	6.0	11.7	62	40
Northern Great Plains	7,941	23.9	18.0	9.1	2.6	11.7	12.2	75	51
Southern Great Plains	10,236	27.1	25.3	15.5	5.1	20.6	6.5	93	61
Total	40,958	159.7	122.7	65.5[1]	21.1	86.6	73.1	77	53
Acre-feet/acre		3.90	3.0	1.60	0.52	2.11	1.78		
Year 2000 — continuation of ongoing program assuming full water supply									
Northwest	5,513	27.5	18.3	9.1	2.7	11.8	15.7	67	50
Southwest	11,216	44.1	39.4	25.8	6.4	32.2	11.9	89	65
Intermountain	2,042	8.5	7.2	3.4	0.9	4.3	4.2	85	47
Rocky Mountain	4,010	18.7	12.3	5.4	1.6	7.0	11.7	66	44
Northern Great Plains	7,941	22.3	17.8	10.4	2.1	12.5	9.8	80	58
Southern Great Plains	10,236	25.9	24.4	15.7	4.3	20.0	5.9	94	64
Total	40,958[2]	147.0	119.4	69.8	18.0	87.8	59.2	81	58
Acre-feet/acre		3.59	2.92	1.70	.44	2.14	1.45		
Year 2000 — installation of program shown in table 15 assuming full water supply									
Northwest	5,513	20.3	15.5	9.1	2.1	11.2	9.1	76	59
Southwest	11,216	39.2	35.2	25.8	4.8	30.6	8.6	90	73
Intermountain	2,042	7.2	6.3	3.4	0.7	4.1	3.1	88	54
Rocky Mountain	4,010	14.2	10.6	5.4	1.3	6.7	7.5	75	51
Northern Great Plains	7,941	17.4	15.5	10.4	1.6	12.0	5.4	89	67
Southern Great Plains	10,236	22.8	22.0	15.7	3.0	18.7	4.1	96	71
Total	40,958	121.1	105.1	69.8	13.5	83.3	37.8	87	66
Acre-feet/acre		2.96	2.57	1.70	0.33	2.03	0.92		

[1] 4.3 million acre-feet shortage.

[2] Irrigated acres for year 2000 were held constant to better show effects of water conservation measures. See Second National Water Assessment report for projections of irrigated acreage.

However, net depletions would increase by 1.2 million acre-feet.

Measures by Characterization Areas

The Soil Conservation Service study shows that the kinds and amounts of measures that would help solve the irrigation use problems vary considerably from area to area. These are shown in table 15 for the six characterization areas described in chapter 1, with the costs of installing the measures.

Off-farm conveyance systems improvements are the prime measures in the northwest area. Canal and lateral lining and piping, along with consolidation, realignment, and enlargement of canals, are the measures of primary concern. Onfarm measures of major importance are change in method, automation, and ditch lining or piping.

For the southwest area, measures for off-farm and onfarm are well balanced in terms of solutions. In addition to canal lining (which is the major off-farm measure in all areas), consolidation, realignment, and enlargement are important. Automation, ditch lining, land leveling, tailwater recovery systems, and control structures all are important onfarm measures. In this

Table 15.—*Measures and costs for characterization areas, 17 western States.* (Source: Soil Conservation Service studies.)

Measure	Units (1,000)	Northwest		Southwest		Intermountain		Rocky Mountain		Northern Great Plains		Southern Great Plains		17 Western States	
		Quantity	Total cost[1] $ million	Quantity	Total cost[1] $ million	Quantity	Total cost[1] $ million	Quantity	Total cost[1] $ million	Quantity	Total cost[1] $ million	Quantity	Total cost[1] $ million	Total quantity	Total cost[1] $ million
Off-farm															
Consolidation, realignment & enlargement	feet	5,951.2	100.8	5,766.1	668.9	3,116.4	12.4	18,109.5	60.7	8,391.8	22.7	1,188.3	2.0	42,522.9	867.5
Lining & piping	feet	22,858.1	942.9	34,769.1	2,007.9	8,260.5	165.4	39,397.0	1,078.3	48,974.0	665.1	5,815.7	207.2	160,074.4	5,066.8
Control structures	each	23.1	81.2	4.1	8.0	5.9	20.5	42.8	123.1	10.6	41.7	6.8	5.1	93.3	279.6
Subtotal			1,124.9		2,684.4		198.3		1,262.1		729.5		214.3		6,213.9
Onfarm															
Lining & piping	feet	43,390.9	137.1	182,716.8	871.6	25,984.1	152.0	49,449.2	252.7	64,866.8	230.3	111,295.2	374.0	477,703.0	2,017.7
Land leveling	acres	338.9	50.9	4,534.9	678.3	487.7	54.0	558.3	90.0	1,458.1	260.0	4,238.6	813.0	11,616.5	1,946.2
Control structures	each	134.7	39.6	4,547.4	452.8	121.4	10.4	176.5	38.1	403.5	121.2	82.8	33.8	5,466.3	695.9
Change of method	acres	1,110.2	419.5	177.7	53.0	610.4	162.1	989.8	272.2	404.4	116.3	227.2	47.4	3,519.7	1,070.5
Tailwater recovery	acres	963.4	49.1	6,873.8	333.9	72.7	4.6	56.7	3.3	2,854.3	156.8	4,932.5	201.7	15,753.4	749.4
Irrigation water management	acres	2,620.2	13.1[2]	8,888.9	44.4[2]	1,826.4	9.1[2]	3,186.8	15.9[2]	4,792.5	24.0[2]	7,103.3	35.5[2]	28,418.1	142.0[2]
Automation	acres	815.4	166.2	10,228.3	1,022.3	285.1	12.1	192.1	22.6	2,688.6	346.7	6,431.6	330.8	20,641.1	1,900.7
Subtotal			862.4		3,411.9		395.2		678.9		1,231.3		1,800.7		8,380.4
Total Cost			1,987.2		6,096.7		593.5		1,941.0		1,960.8		2,015.0		14,594.3

[1] This is a one-time cost. 1977 price base.
[2] This is an annual recurring cost and not included in the subtotal and total costs.

area where irrigation efficiencies are generally the highest in the West, a primary measure for further improvement is automation, estimated for 10 million acres.

In the intermountain area the inventory showed that more work needs to be done onfarm than on distribution systems. The major improvements are change in method, primarily to sprinkler, lining or piping of ditches, and land leveling for improvement of surface systems. The major improvements in off-farm conveyance systems would be the lining or piping of canals and laterals and water control structures.

In the Rocky Mountain area, the off-farm measures are more costly than the onfarm. Canal and ditch lining, both off-farm and onfarm, are the most important measures, along with change in method and land leveling onfarm.

Onfarm measures are the primary concern in the northern Great Plains, as much of the water supply is from ground-water pumping; tailwater recovery systems, automation, and land leveling are most important. Lining of canals is the most costly off-farm measure.

In the southern Great Plains, the onfarm measures, again, are the primary need as most of the water is self-supplied. Automation, tailwater recovery systems, and land leveling are the major measures to be installed.

In all 17 western States, irrigation water management, including scheduling, is an important nonstructural measure. Better management of the water onfarm would improve 28.4 million acres. Automation is needed on 20.6 million acres, tailwater recovery systems on 15.8 million acres, and land leveling on 11.6 million acres. The single most costly measure is canal and lateral lining and piping of off-farm conveyance systems. This is estimated to cost $5.1 billion, or about 35 percent of the total program. The onfarm costs are well balanced between ditch lining, land leveling, and automation as to the most costly measures.

The one-time cost for installing these measures in the 17 western States was estimated to be $14.6 billion (table 15). Of this amount, $6.2 billion is for off-farm improvements, and $8.4 billion for onfarm improvements. Onfarm irrigation water management, an annual cost, was estimated to be $0.14 billion.

Impacts of Measures

The program of measures outlined in table 15 will have some definite impacts on water conservation, irrigation efficiencies, the environment, and the economic and social structure of the West. With the implementation of such a program, significant changes could occur in the hydrology in some basins. In addition to shifts in the water budget shown in table 14, changes in instream flow, wildlife habitat, and water quality are to be expected. Often onsite benefits are not sufficient to justify extensive water conservation programs. However, consideration of offsite benefits, water quality improvements, addition to instream flows, and allocation of salvaged water to subsequent uses could make a major conservation program feasible.

Some types of environmental, economic, and social impacts accrue to all areas as a result of implementing water conservation programs. There will be changes in streamflow patterns with both beneficial and adverse effects on existing fisheries and other instream uses. Generally, more water would be available in the streams, but the location and timing would be modified. Water quality could be improved if less salts, nutrients, and sediment were removed from the irrigated areas. However, concentrations of remaining pollutants could be greater in the reduced return flows, possibly causing some localized water quality problems. Where water losses are stemmed, reducing adjacent wetlands and phreatophytes and hydrophytes dependent on high water tables caused by excessive water application, less wildlife habitat of some types will be available without mitigation efforts.

Water conservation programs have a predominantly beneficial impact on gross crop production, value of production, and improvement in the economic base associated with irrigation. With the reduction of diversions should come a reduction in the cost of pumping and transporting water for irrigation, even though more sophisticated systems generally will be required. In some areas, improvement in irrigation water management can also yield environmental gains.

Environmental Impacts

Implementing the measures in table 15 would result in three major effects on the water budget as shown on figure 7 and in table 14: (1) a reduction in water withdrawals or diversions, (2) a reduction in the irrecoverable or incidental losses, and (3) a reduction in return flows. Environmental impacts of these effects are both widespread and localized, as shown in table 16. Widespread impacts are discussed below, with exceptions and region-specific impacts shown in table 18.

Water Quality. — Increasing the efficiencies of water conveyance systems and onfarm water applications would have a beneficial effect on water quality. This could include a reduction in salinity, sediment, nutrients, and pesticide residuals. Irrigation techniques which either reduce pollutant loading (the addition of pollutants to the system) or reduce concentrating effects (evaporation and transpiration which remove pure water) often will improve water quality. In some situations the goal of improved water quality may be the dominant objective of an irrigation water conservation program.

The primary impact of a reduction in diversions and incidental use could be a reduction of stream pollution concentrations through enhanced assimilative capacity and dilution, assuming the water salvaged remained in the stream. Reduction in return flows would reduce loading of pollutants.

A program to reduce irrigation return flow and the associated salt load from the Wellton-Mohawk Irrigation District was developed in 1974 as an interagency effort of the Bureau of Reclamation, Soil Conservation Service, Agricultural Research Service, and the Environmental Protection Agency working closely with the irrigation and drainage district and the farmers. To reduce return flows and realize savings in desalting costs of return flow, several programs have been implemented. These include improved irrigation measures by the Soil Conservation Service and the acreage reduction program of the Bureau of Reclamation, research and demonstration by the Agricultural Research Service, and education and information program of the Cooperative Extension Service.

The implementation plan developed in 1974 included irrigation scheduling, improving onfarm irrigation systems, and research and education programs on the 65,000 acre project. Average onfarm irrigation efficiency in the district will increase from 56 to an estimated 72 percent. The onfarm irrigation improvement and some land retirement will reduce drainage flow by an estimated 78,000 acre-feet per year, and reduce salt loading by about 500,000 tons per year.

A program was initiated in 1977 by the SCS on 22 farms encompassing 2,920 acres. All conservation practices including irrigation scheduling have been installed. They resulted in an average onfarm irrigation efficiency increase from 59 percent to 88 percent the first year of operation. The reduction in farm delivery for the 2,920 acres was 7,420 acre-feet. Farmers indicate the improvements have generally reduced irrigation labor by 50 percent. Annual savings in water cost varied by field and crop from $5.78 to $58.00 per acre. However, over the long run no savings in total water cost to all irrigators would result unless the cost of operation of the district were reduced because costs of operating the project are fully recovered through water charges.

Ground Water. — The major impact of irrigation on ground-water aquifers in areas where the water is supplied from the aquifer results from consumptive use for crop production or other purposes. In the shallow or moderately deep aquifers, most seepage and surface return flow will find its way back to the aquifer. However, a reduction in this return flow to the ground water generally will reduce the rate of quality degradation. Where water is pumped from deep aquifers, the time of return is slow and questionable. Therefore, the total withdrawal can be considered a depletion of the aquifer. Any reduction in withdrawal demands will prolong the life of these deep aquifers.

Table 16.—*Environmental impacts of implementing water conservation measures on irrigation systems (generally considered as positive effects unless denoted by a minus sign).*

	Intermountain			Southwest			Northwest			Southern Great Plains		Northern Great Plains		Rocky Mountain	
	Mountain meadow	Intermediate valley	Lower valley	Mountain meadow	Intermediate valley	Lower valley	Mountain meadow	Intermediate valley	Lower valley	Intermediate valley	Onfarm	Intermediate valley	Onfarm	Mountain meadow	Intermediate valley
Water quality change - Surface															
salinity of return flow reduced,	0	L	X	0	L	X	0	L	X	L	X	L	L	0	L
Sedimentation reduced,	0	X	X	0	X	X	0	L	L	X	X	X	L	0	L
Pesticide residues reduced,	0	L	X	0	X	X	0	X	X	L	L	L	L	0	L
Nutrients reduced	0	L	X	0	X	X	0	X	X	X	X	X	X	0	L
Available water supply															
Instream flows[1]															
Irrigation season	L	X	X	L	X	X	L	X	X	X	L-	X	L-	L	X
Post-irrigation season	L-	L-	X	L-	L-	X	L-	X	X	X	X	X	X	L-	X
Ground-water aquifer															
Recharge reduced	L	L	L	L	X	X	L	X	X	0	0	0	0	L	X
Relief of depression cones	0	L	L	0	L	L	0	L	L	L	0	L	0	0	0
Fish and wildlife habitat															
Wildlife resource	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Resident fish	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Anadromous fish	0	0	0	L	L	L	X	X	X	0	0	0	0	0	0
Estuaries	0	0	0	D	L	L	D	L	L	L	D	D	0	D	D

[1] Assumes water made available is allocated to instream use to the extent needed.

X = Uniform
L = Local
0 = No Impact
D = Distant
- = negative impact

In areas where conjunctive use of surface and ground water is practiced, or surface water is the primary supply, water conservation programs have a far less significant impact on the ground-water aquifer. The major impact may be on water quality. Irrigation water use and management improvement programs can reduce the rate of delivery of pollutants to the aquifer. To the extent that consumptive use exceeds the surface supply, a reduction in ground-water levels is to be expected. Otherwise, reductions in total withdrawals in these situations are expected to have little effect on ground-water supplies.

The interrelationship of ground and surface water in southwestern Nebraska is an example of the delicate balance between ground and surface water supplies. Ground-water discharge has historically supplied a major part of the streamflow in the area. With the advent of center-pivot irrigation using ground water, land previously considered not irrigable was developed in the late 1960's. As a result, by 1975 the streamflow of Frenchman Creek near Imperial was reduced by about 30 percent.[6]

Enders Reservoir stores water for irrigation use farther downstream. The water is released when needed and flows down Frenchman Creek until it is diverted by canal to the irrigated area. Downstream prior rights to the waters of Frenchman Creek date back to 1890. The irrigation districts holding these rights also hold most of the water storage rights in Enders Reservoir.

A recent study of three counties in southwestern Nebraska[6] developed a hydrologic model of the area and simulated the impact of future irrigation development. Analyses made with the model assumed that all water withdrawn from the ground-water aquifer, but not consumptively used by the crop, returned to the ground-water aquifer. This assumption implies that any water lost through evaporation reduces the crop irrigation requirement by an equivalent amount due to the effect of the evaporation in the microclimate, thus resulting in zero net evaporated loss. Any runoff from irrigation is assumed to re-enter the aquifer through infiltration and deep percolation.

The hydrologic model was used to estimate the reductions in ground-water level and streamflow in the future under two assumptions. The first assumption was that there would be no additional irrigation development beyond that established in 1975. The second assumption was that irrigation development would continue at the 1975 rate of development subject to available irrigable land. Under the second assumption, Frenchman Creek near Imperial would be dry before 1995.

The benefits of improving irrigation efficiency would be reduced energy use, since the total water pumped would be reduced, and possibly a crop yield increase. There may be some net gains to be made by reducing evaporation loss, assuming that not all water evaporated during the irrigation process is effectively used in reducing crop consumptive use. There might also be a change in the time and place that both surface and ground water are available for use by others.

Keeping in mind societal goals of energy conservation, water quality maintenance or improvement, instream flow requirement, and maximizing food production from available water resources, programs which would encourage pump irrigators to alter land use or to utilize irrigation scheduling techniques could reduce water use and energy use considerably. Although further study is definitely required before implementing these or other alternatives, it is obvious that some program must be undertaken to minimize the possibility of a future crisis in this area.

Instream Flows. — Implementing measures to improve irrigation efficiencies could improve instream flows. Reductions in noncrop consumptive use as a result of improved irrigation water use and management offer only marginal opportunity to improve instream flows during critical periods. Assuming that reduced diversions will be used to increase instream flows where the need can be demonstrated, the impacts can generally be described as follows:

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[6] "Quantitative Hydrogeology of the Upper Republican Natural Resources District, Southwest Nebraska." Unpublished manuscript by Eric Lappala, Geological Survey, in cooperation with the Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, and Upper Republican Natural Resources District. p. 214.

1. Improved instream flow conditions between the point of diversion and the point of return flow during the irrigation season.

2. Where storage capacity is available or could be built, the water not needed for diversion could be retained in storage for release to improve instream flow conditions (and provide freshwater inflow to estuaries in localized areas) during periods of deficit (nonirrigation season and in drought years). In both of these situations, the benefits would include increased carrying capacity for fish and aquatic and riparian wildlife populations, river-dependent outdoor recreation use, waste assimilation, sediment transport (with attendant reduction for river dredging costs to aid navigation), possible increased hydropower generation (dependent on relative location of plants and market situation), and improved estuarine circulation and salinity balance (which in some cases have been severely altered by past irrigation developments to the detriment of commercially significant fish and shellfish production).

3. Reduction of return flows can have the negative impact of losing the desirable extension of streamflow duration into the late summer and fall months, which has resulted from current irrigation practices in some localities.

4. In some basins, what appear to be excessive diversions are being made to reduce spring flood damages. This use of irrigation systems for a nonirrigation purpose provides social benefits. Care should be taken to avoid including such diversions in computing irrigation system efficiencies.

Alternatively, if we assume the salvaged water is reallocated to irrigation, thermoelectric cooling, or other consumptive municipal or industrial uses, the impacts could be very different, depending on the location of diversion for the new uses. The impact could be similar if the new point(s) of diversion is downstream from the previous return flow point(s). But the impact could be negligible if the same diversion point(s) is used. A site analysis is necessary to determine potential positive or negative effects on instream values.

Wildlife. — Implementation of efficient irrigation water management methods can have a significant impact on wildlife habitat. While there are different wildlife species in the various characterization regions and irrigation settings, these impacts can be generalized by discussing the major wildlife groups.

Waterfowl, shorebirds, herons, and other species dependent upon wetlands and seeps would suffer loss of habitat to the extent that such areas are maintained by conveyance losses, tailwaters, and operational spills. There would be significantly less wildlife habitat associated with irrigation water use, without mitigation.

Removal of phreatophytes to reduce incidental losses would have an adverse impact on nesting waterfowl, upland game, small mammals, and songbirds and other nongame animals. Also, drainage ditches and wasteways provide habitat for many game and nongame species. Reduction of excess diversions and irrigation applications can be expected to reduce or change the value of these areas.

Threatened and endangered species inhabit some irrigated regions and may have adverse responses to the effects of implementing water conservation measures. Specific studies would be required to establish whether such responses would occur and to formulate compensating measures to ensure the continued existence of these populations and their habitats.

Big game animals (especially deer) and other terrestrial wildlife have drowned in large, lined canals. Design of such structures in wildlife migration areas should incorporate features to permit escape or safe crossing.

Fish. — Some impacts on fish have been described in the discussion of instream flows and water quality. However, a more accurate picture of the impact of irrigation (and hence irrigation efficiency measures) can be presented by considering resident fish and anadromous fish separately.

Resident fish live their entire life spans in a local area (stream reach, reservoir, and in some cases both). The well-being of stream fisheries is directly influenced by the instream flow conditions. Some species are intolerant of changes in their environment as may occur from implementation of the previously described measures. Other species are very tolerant of such changes. Generally, the more desirable game fish are less tolerant than the "rough" fish. Therefore, shifts in species composition can be expected and, depending on the local conditions, could be deemed either desirable or undesirable. Reservoir fisheries may benefit from water conservation measures that result in reducing reservoir drawdown and improving quality of inflows.

Anadromous fish spend a part of their lives in saltwater, but return to freshwater to reproduce. They are found in many of the tributary streams flowing into the Nation's coastal waters, but of primary importance in this study are those streams tributary to the Pacific Ocean. Important anadromous fish include several salmon species, steelhead trout, smelt, sturgeon, and striped bass. Many of the streams in the mountain meadow, intermediate valley, and lower valley areas in California, Washington, Oregon, and Idaho provide the desired spawning, incubation, and rearing areas in addition to passageways for anadromous fish species. Reducing water diversions by implementation of efficient water use and management methods could significantly contribute to maintenance of critical instream flows in waters tributary to the Pacific Ocean. In the mountain meadow setting of the Pacific Northwest, efforts to improve irrigation efficiency could be coupled with efforts to keep salmon and steelhead fingerlings and smolts from being diverted onto irrigated lands to perish. This could be an opportunity for farmers to improve diversion structures using Federal funds directed toward preservation of anadromous fish stocks.

Water and power developments in California have had a significant impact upon migrations of salmon and steelhead smolts in addition to striped bass. By implementing improved water management methods in the intermediate and lower valleys, additional water could be made available for improved instream flows for spawning, incubation, and rearing of juveniles at critical times. There would be enhanced assimilative capacity of pollutants with increased streamflows and a reduction of pollutants to the estuaries from reduction of return flows from agricultural areas. This reduction of sedimentation and pesticide residues would greatly assist in sustaining, protecting, and perhaps perpetuating the biotic communities common to the estuarine environment. Maintenance of this estuarine habitat is critically important to anadromous fish. The potential increase in survival would provide beneficial impacts to the commercial and sport fishing industry. In addition, there is aesthetic value for people who enjoy nonconsumptive uses of the migrating fish species (i.e., observing fish concentrations). The increased survival would assist in the perpetuation of specific races of fish species, thus keeping them off the Endangered and Threatened Species List.

Economic and Social Impacts

Implementation of irrigation water conservation measures may provide opportunity to meet additional water needs. These could include increased hydroelectric power production during critical periods, minimum streamflows for multipurpose uses, increased and sustained agricultural production, fish and wildlife habitat and recreational uses, improvement of water quality, navigation, estuarine inflows, and municipal and industrial development.

Although it is impossible to arrive at exact estimates for a general program over the 17-State area, nonetheless there are real benefits that can be evaluated in detail when specific projects are undertaken.

An example of the type of site-specific studies which could be used to estimate the benefits and costs to the agricultural sector of a set of conservation measures is the study done in the upper Snake River Basin.[7] This study evaluated alternative delivery and onfarm distribution systems for an irrigation project in Bingham County, Idaho. The major crops grown in this area are alfalfa, spring grains, and potatoes. The Snake River serves as a source of water supply with water presently being delivered by a series of canals. The majority of the onfarm irrigation systems have unlined ditches and use either the border or furrow method of irrigation.

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[7] "Irrigation Water Distribution and Use, a Case Study, Upper Snake River Basin, Idaho," prepared by USDA, SCS, ERS, and FS, June 1978.

The study evaluated a number of alternative combinations of delivery systems and onfarm irrigation systems. Table 17 presents a comparison of the project irrigation efficiencies, costs, and benefits for the present situation and nine selected alternatives. The first alternative is to continue using the present method with no change. Each of the remaining eight alternatives incorporates varying levels of either improved onfarm irrigation systems or improved distribution systems.

One of the major benefits of improving the onfarm irrigation system is the increase in crop yields with a corresponding improvement in the net returns to management, overhead, land, and water. The annual project costs include both the onfarm application system costs and the distribution system costs. Both the costs and benefits in table 17 are based on the present crop distribution pattern. The change in primary net benefits compared to alternative 1 is presented at the bottom of the table. Given the present system-wide crop distribution, alternative 5, which involves improving surface irrigation systems throughout the area, shows the greatest economic gain in primary net benefits.

Although alternative 9, which involves 100 percent conversion to sprinklers, shows a net loss in primary net benefits given the present crop distribution, it may still be economically feasible. Adjustments can be made in the crop distribution which would increase the net returns from each of the onfarm application systems. The net returns, application system costs, and the balance were evaluated for

Table 17.—*Annual net benefits for project alternatives.* (Source: "Opportunities to Improve the Efficiency of Irrigation Water Distribution and Use. A Case Study Upper Snake River Basin, Idaho." Prepared by: USDA, SCS, ERS and FS, August 1977.)

	Selected alternatives								
	1	2	3	4	5	6	7	8	9
	Future without						Progressive		
Project efficiency (percent)	21.4	30	35	40	45	51	21.4/40	51	62
On-farm application system									
Unimproved gravity (% of area)	100	56	36	18	0	0	18	6	0
Improved gravity (% of area)	0	44	64	82	100	0	82	94	0
Sprinklers (% of area)	0	0	0	0	0	100	0	0	100
Distribution system type (all reaches)	Unlined	Unlined	Unlined	Unlined	Unlined	Unlined	Unlined	Lined	Lined
Annual primary benefits									
Net returns to management, overhead, land, and water ($/acre)	138.97	163.33	174.40	184.37	194.34	200.10	167.55	191.02	200.10
Annual project costs									
Application system costs ($/acre)	14.76	23.80	28.28	33.36	37.74	75.44	26.56	36.23	75.44
Distribution systems costs ($/acre)	9.60	8.89	8.33	7.84	7.64	7.40	8.67	28.48	27.37
Total project costs ($/acre)	24.36	32.69	36.61	41.20	45.38	82.84	35.23	64.71	102.81
Annual primary net benefits									
Net returns to management, overhead, land, and water ($/acre)	114.61	130.64	137.79	143.17	148.96	117.26	132.32	126.31	97.29
Change in primary net benefits ($/acre)	0	16.03	23.18	28.56	34.35	2.65	17.71	11.70	-17.32

10 alternative crop distributions. The relative ranking of economic gains of the nine systems varied with the cropping patterns. Irrigators could therefore select crop rotation and onfarm application systems which meet individual requirements, which will vary depending on farm size, managerial ability, risk, type of business enterprise, and personal preference.

This study is an example of one method of evaluating the economic feasibility of a number of alternative irrigation delivery and onfarm application system improvements for a specific site. The study also compared project irrigation efficiency for each of the alternatives. However, in addition to these factors, the impacts of each of the possible alternatives on wildlife habitat, ground-water recharge, instream flow, and water quality must be considered before some water conservation measures can be implemented. The complexity of this example may exceed that of many sites; however, others may be even more complex due to ground-water recharge, wildlife habitat, and other conjunctive uses of water.

Impacts by Characterization Areas

The material in table 18 summarizes the estimated impacts of implementing the irrigation water conservation measures shown in table 15. Impacts are included for water budget changes, improvement in efficiencies, the environment, economic/social, and other.

While recommendations on Federal policies, objectives, and action programs will be addressed elsewhere in the report, it is noted that substantial institutional changes and financial support will be necessary to implement an accelerated water conservation program as set forth in this chapter. Also, it will be necessary to carry out detailed studies and assessments of specific areas before implementation is considered. As pointed out in the Water Conservation Opportunities study of the Department of the Interior, only some project improvements appear justified based on current water resources project evaluation. The impact evaluation summarized here should in no way be considered a justification for or against the general program presented for the 17 western States. However, it does show the types of impacts and a range of magnitude for some. Neither is the program presented as a specific set of measures to be implemented. But it is indicative of the kinds and general amounts and costs of measures necessary, should an accelerated national program be undertaken.

Explanation of Economic Benefits Estimated

Reduced Diversions. A reduction in water diverted for irrigation could result in a reduced cost for the irrigator or irrigation district. This might take the form of reduced cost of energy as a result of less pumping; less operation, maintenance, and replacement of facilities; and reduced drainage. Cost savings have been estimated based on reduced pumping.[8]

Improved Farm Income. In most cases, crop production increases and/or reduced costs should result from improving irrigation water use and management. Better management of water onfarm results in less soil, fertilizer, and pesticide loss; increases in yield and quality of produce; and, depending on the system, a reduction in labor. A detailed farm budget is needed to estimate the benefits in specific cases.

An examination of selected river basin studies reveals that the change in irrigation efficiency can be used to estimate the percent increase in farm income associated with improvement measures. The estimates of net return to land, family labor, and management are based on Economics, Statistics, and Cooperatives Service crop budgets developed which were weighted by the estimated land use within the area. The increase in farm income relative to increases in efficiencies would be expected to vary with the mix of structural measures to be installed; however, due to a lack of data, no adjustments are made. Diminishing returns to improvement measures would be expected as efficiencies increase.

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[8] "Energy and U.S. Agriculture; Irrigation Pumping," Sloggett, Gordon, USDA, ERS, Agricultural Economic Report No. 376. 1974.

Incidental Consumptive Use. A reduction in incidental consumptive use could make more water available for agriculture or nonagricultural consumptive purposes as well as for instream use. The value of this water varies greatly, depending on the location and competition for use. In basins where there are junior appropriators without adequate supplies, the use may be predicted. In this study a measure of the economic value of the water was assumed to be equal to its use in agriculture. However, in some cases additional storage or development cost will be incurred before it can be used. In other cases, the installation of a sound irrigation water use and management program will firm up the water supply throughout the growing season, and thus additional water will be used onsite. Other reductions in incidental uses may be left instream or diverted for municipal and industrial or additional agricultural use.

Other Off-site (Downstream) Benefits. Another downstream benefit from improved irrigation water use and management is salinity control. This has been estimated for the intermountain and southwest areas. Studies made as a part of the Colorado River Basin Salinity Control program have been used as a basis for the values used in these estimates.[9] Instream economic benefits which might be evaluated include additional hydropower generation, additional fishing or recreation days, other forms of use of improved streamflow or water quality conditions, and flood control.

Increased Employment. Estimates have been made of both the additional jobs and income resulting from the installation of the water conservation measures during the construction period. The estimates were based on studies conducted by the Economic Development Administration.[10]

Increased Regional Income. The increase of regional income was based on a national type I multiplier developed by the Economics, Statistics, and Cooperatives Service. There may be some offsetting decreases in other regions.

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[9] "Economic Impacts of Changes in Salinity Levels of the Colorado River," USDI, Bureau of Reclamation, Denver, Colorado. Prepared by Alan P. Kleinmen, Glade J. Barney, and Sigurd G. Titmus, February 1974.

[10] "An Evaluation of Public Works Impact Program (PWIP)," Economic Development Administration, Washington, D.C. 1975.

Table 18. — *Impacts by characterization areas*

Northwest Area

Type of Impact	Onfarm	Off-farm	Total
	(million acre-feet)		
Water budget[1]			
Reduction in diversions	4.9	8.1	13.0
Reduction in incidental uses	0.3	0.5	0.8
Reduction in return flow	5.6	7.6	13.2
Increase in crop use	1.0	—	1.0
Improvement in efficiencies (percent)	19	15	

Environment

— Increased flow below mountain meadow areas in spring and summer, but reduced instream flow later in season.

— Reduction in diverted water would increase spawning areas and leave more water instream for fisheries through and below intermediate valleys.

— Decrease in the loss of anadromous fish fry from "wild flooding" of meadows.

— The effect on estuaries would be positive due to more freshwater inflow.

— Less total nutrient load and sediment in return flows would improve water quality.

— Some loss in wildlife habitat in intermediate valley irrigated areas.

— Improved aesthetic value at Shoshone Falls on the Snake River.

Economic/Social

— Cost of program — $2.0 billion.

Onsite

— Increase in net value of farm output is estimated to be $80 million annually.

— Decreased O&M of irrigation systems.

— Estimated overall reduction in energy requirement of about $18 million.

— Improved water supply in water-short areas.

Offsite

— Employment benefits resulting from program construction of about $10 million annually.

— Increased power production with greater streamflow.

— Improvement in navigation.

— Improvement in the commercial and sport fisheries for Pacific salmon.

— Employment resulting from program construction of 29,000 person-years.

— The increased agricultural income would generate an additional $90 million increase in regional income.

Other

— Increased storage needed in some areas, but less demand on some existing storage.

— Reduced ground-water recharge.

— Effect on some water rights.

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[1] Data based on values in Table 14.

Table 18. — *Continued.*

Southwest Area

Type of Impact	Onfarm	Off-farm	Total
	(million acre-feet)		
Water budget			
Reduction in diversions	6.7	4.3	11.0
Reduction in incidental uses	2.0	1.2	3.2[1]
Reduction in return flow	4.8	3.1	7.9
Increase in crop use	0.1	—	0.1
Improvement in efficiencies (percent)	12	7	

Environment

— Reduced diversions would improve freshwater inflow to estuaries.

— General wildlife habitat reduction in irrigated areas.

— Improved aesthetic value of water resources.

— Improvement in water quality affected by nutrients and salts.

— Increased instream flows would benefit anadromous and other fish.

— Reduced salinity loading in the Colorado River.

Economic/Social

— Cost of program — $6.1 billion, one-time installation cost.

Onsite

— Estimated savings in energy use at about $40 million annually.

— Increase in net value of farm output is estimated to be $200 million annually.

— Improved water supply in water-short areas.

— Decreased O&M of irrigation systems.

Offsite

— A measure of the economic value of saved water of about $180 million annually.

— Salinity benefits at about $100 million annually.

— Reduced subsidence caused by pumping if conservation results in less ground-water overdraft.

— Employment benefit as result of the construction program of about $30 million annually.

— Reduced saltwater intrusion.

— Extended life of ground-water aquifer valued at about $15 million annually.

— Increase regional income of about $220 million generated from increased agricultural income.

— Employment resulting from program construction of about 90,000 person-years.

— Improvement of commercial and sport fisheries in the San Francisco Bay and of the coast.

Other

— Make possible better balance between surface and ground-water use.

— Possible impact on some downstream water users: (a) adverse change in flow patterns where storage is not available; (b) improved water quality.

— Decreased ground-water recharge in some areas.

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[1] A more recent study in California (*Water Conservation in California*, May 1976, Bulletin No. 198) indicates that the sum of potential basin-wide water savings, excluding the Tulare Basin, is 1.17 million acre-feet per year, much of which is reused in the Sacramento-San Joaquin River Delta. Thus, only a minor portion would be available for other uses. The amount available could be as low as 540,000 acre-feet per year.

Table 18 — *Continued.*

Intermountain Area

Type of Impact	Onfarm	Off-farm	Total
	(million acre-feet)		
Water budget			
Reduction in diversions	-0.1	0.4	0.3
Reduction in incidental uses	0.1	0.1	0.2
Reduction in return flow	0.5	0.3	0.8
Increase in crop use	0.7	—	0.7
Improvement in efficiencies (percent)	10	5	

Environment

— Increase in early season instream flow below mountain meadows, but decrease in late season flows — less return flow entering terminal lake areas.

— Reduction in wildlife habitat associated with over-irrigation or seepage areas.

— Improvement of water quality — less leaching of salts and nutrients and less sediment from irrigated areas in intermediate valleys.

Economic/Social

— Cost of program — $590 million, one-time installation cost.

Onsite

— Decreased O&M of irrigation systems.

— Increase in quantity and quality of production, improving net farm income about $20 million annually.

— Decrease in energy for ground-water pumping — increase in energy due to system change to sprinklers.

Offsite

— Employment benefits resulting from program construction of about $3 million annually.

— Estimated salinity benefits of about $40 million annually.

— Employment resulting from construction program — 9,000 person-years.

— The increased agricultural income would generate an additional $20 million increase in regional income.

Other

— Extended ground-water supply (due to reduction in incidental use).

— Requires additional water storage.

— Possible impact on some downstream water users: (a) adverse change in flow patterns where storage is not available; (b) improved water quality.

Table 18. — *Continued*

Rocky Mountain

Type of Impact	Onfarm	Off-farm	Total
	(million acre-feet)		
Water budget			
Reduction in diversions	0.3	3.2	3.5
Reduction in incidental uses	0.1	0.2	0.3
Reduction in return flow	1.2	3.0	4.2
Increase in crop use	1.0	—	1.0
Improvement in efficiencies (percent)	11	13	

Environment

— Increased streamflow in early season, but reduced streamflow in late season from mountain meadow.

— Adverse impact on wildlife habitat in intermediate valley irrigated areas and mountain meadows.

— Slight increase in water quality.

Economic/Social

— Cost of program — $1.9 billion, one-time installation cost.

Onsite

— Decreased O&M of irrigation systems.

— Improvement in economic base as crop production increases and is stabilized through firmed-up water supplies, valued at about $25 million annually.

— Savings in energy use of about $1 million annually.

— Improved water supply in water-short areas.

Offsite

— Increased chance of downstream spring flooding as less water is diverted in mountain meadow areas.

— Employment benefits from program construction of about $6 million annually.

— Some additional storage required.

— Salinity benefits will occur, but were not evaluated.

— Employment resulting from program construction of 28,000 person-years.

— Increase in agricultural income would generate $30 million of additional regional income.

Other

— Possible impact on some downstream water users: (a) adverse change in flow patterns where storage is not available; (b) improved water quality.

Table 18. — *Continued*

Northern Great Plains

Type of Impact	Onfarm	Off-farm	Total
	(million acre-feet)		
Water budget			
Reduction in diversions	2.5	4.0	6.5
Reduction in incidental uses	0.4	0.6	1.0
Reduction in return flow	3.4	3.4	6.8
Increase in crop use	1.3	—	1.3
Improvement in efficiencies (percent)	16	14	

Environment

— Improved instream flow conditions between point of diversion and point of return flow.

— Assist in protection of vital habitat of the sandhill crane and the endangered whooping crane populations along the Platte River.

— Reduced fluctuation in instream flows.

— An opportunity exists for "saved" water in storage to be available for other uses such as instream flow, power, recreation, agriculture, and M&I.

— Reduced wildlife habitat in some irrigated areas.

— General improvement in water quality, including sediment, salinity, and pesticides.

Economic/Social

— Cost of program — $2.0 billion, one-time installation cost.

Onsite

— Increase in net value of farm output of about $130 million annually.

— Estimated saving in energy use of about $25 million annually.

— Decreased O&M of irrigation systems.

— Improved water supply in water-short areas.

Offsite

— Extend life of ground-water aquifers in general, but reduce ground-water recharge in some areas; is valued at about $8 million annually.

— Estimated employment benefits resulting from program construction of about $4 million annually.

— Employment resulting from construction program of 29,000 person-years.

— Increase in agricultural income would generate an additional $90 million increase in regional income.

Other

— Reduction in sprinkler evaporation losses.

— Possible impact on some downstream water users: (a) adverse change in flow patterns where storage is not available; (b) improved water quality.

Table 18. — *Continued*

Southern Great Plains

Type of Impact	Onfarm	Off-farm	Total
	(million acre-feet)		
Water budget			
Reduction in diversions	3.3	1.0	4.3
Reduction in incidental uses	1.6	0.5	2.1
Reduction in return flow	1.9	0.5	2.4
Increase in crop use	0.2	—	0.2
Improvement in efficiencies (percent)	10	3	

Environment

- Improved instream flow conditions between point of diversion and point of return flow.
- Improved freshwater inflows to estuaries along Texas coast.
- An opportunity exists for "saved" water in storage to be available for other uses such as instream flow, power, recreation, agriculture, and M&I.
- Some wildlife habitat reduction in irrigated areas.
- General improvement in water quality with reduction in return flows.
- Potential for wildlife management at some playa lakes.

Economic/Social

- Cost of program — $2.0 billion, one-time installation cost.

Onsite

- Increase in net value of farm output of about $90 million annually.
- Reduced pumping cost and energy requirements of about $25 million annually.
- Decreased O&M of irrigation systems.
- Improved water supply in water-short areas.

Offsite

- Estimated employment benefits resulting from program construction of about $5 million annually.
- Extend life of ground-water aquifers, a value of about $30 million annually.
- A measure of the economic value of "saved" water valued at about $135 million annually (for agricultural use).
- Additional increase in regional income of $100 million annually generated by additional agricultural income.
- Employment resulting from construction program of 30,000 person-years.
- Gains from increased freshwater inflows to Galveston Bay and other estuaries could offset the other economic losses presently realized by the shrimp industry.

Other

- Reduced losses to non-recoverable groundwater aquifers.
- Some reduction in evaporation loss from sprinklers.
- Some reduction in storage needs.
- Possible impact on some downstream water users: (a) adverse change in flow patterns where storage is not available; (b) improved water quality.

Chapter 6
Special Problems in the Humid Area

Irrigation in the humid area of the United States is a fairly recent development. Except in Florida where water table control has been practiced for many years with open ditches, and in the rice-growing States of Arkansas, Louisiana, and Mississippi, irrigation development in the humid area has primarily occurred since World War II.

Of the approximately 8.5 million acres irrigated in the humid area, about 4 million acres are surface irrigated. This acreage is increasing, but it was the development of lightweight aluminum tubing in the forties and the development of center-pivot and cable-tow sprinkler systems in the sixties that provided impetus to irrigation growth in the East.

Until the sixties, practically all sprinkler irrigation was used on high cash value crops such as tree fruits, berries, vegetables, tobacco, nursery stock, flowers, and turf. In the last several years, the mechanical move systems have been adopted and sizable acreages of corn, peanuts, and soybeans are being brought under irrigation.

Droughts have been experienced during the last 15 years, but the drought in 1976-77 was especially severe. This has provided additional stimulus to irrigation growth.

Irrigation is an essential practice in certain portions of the humid area such as the sandy coastal areas, areas adjacent to the lower Mississippi Valley, and in the dry regions in Hawaii and the Caribbean. Elsewhere, irrigation is necessary for improved economic production. Throughout the area, irrigation is necessary to improve crop yield and quality and to reduce the risk of crop failure.

Data for this chapter were obtained from a survey prepared by the Technical Work Group and distributed to the Soil Conservation Service state conservationist and the extension irrigation specialist in each State in the study area. Consequently, the data are representative of the 1977 growing season.

Area Characterization

The humid area of the United States for the purposes of this study consists of the 31 continental eastern States, Hawaii, Alaska, and the Caribbean. The line dividing the 31 eastern States from the 17 western States is defined as the eastern State line of Texas, Oklahoma, Kansas, Nebraska, South Dakota, and North Dakota.

The humid area of the continental United States is further divided into six characterization areas. The divisions are based primarily on similarities of land forms and soil associations. They are Coastal Flatwoods, Coastal Plains, Lower Mississippi Valley, Eastern Uplands, Corn Belt, and Lake and Drift Plain. The western boundaries of the characterization areas are not coincident with the State boundaries as previously defined, but the data presented herein are limited to State boundaries. Alaska, Hawaii, and the Caribbean are presented individually. (Figure 20.)

Coastal Flatwoods

The Coastal Flatwoods lie wholly within the coastal plain physiographic province. The land surface is generally quite flat with slopes often averaging 1 foot per mile or less. The area is characterized by sandy, poorly drained soils (high water tables) interspersed with muck lands that can range from less than 10 percent to 90 percent muck. Average annual precipitation ranges from 48 inches in the north to 60 inches

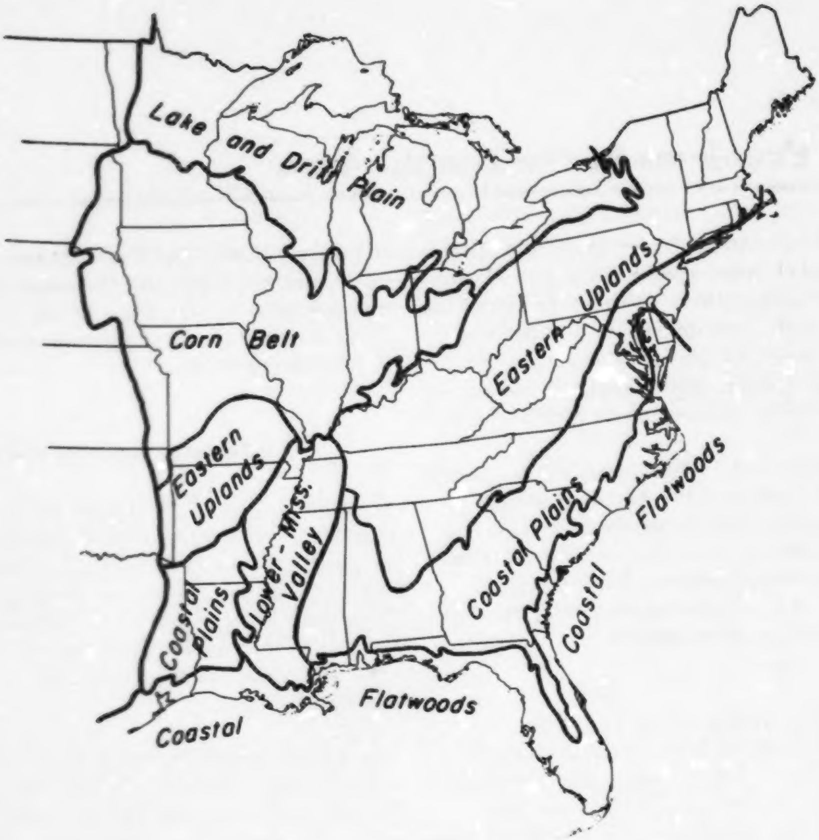
Lake and Drift Plain
Corn Belt
Eastern Uplands
Eastern Uplands
Lower - Miss. Valley
Coastal Plains
Coastal Plains
Coastal Flatwoods
Coastal
Coastal Flatwoods

Figure 20.—Characterization areas, eastern United States.

in the south. The growing season averages 200 days in Delaware and Maryland; 300 days in Alabama, Mississippi, and Louisiana; and in excess of 300 days in Florida. Some of the area consists of marsh and prairie land, primarily along the coastline and near rivers and lakes, the remainder is mainly "flatwoods" containing large areas of pine forests. The predominant land use is agriculture.

Coastal Plains

The Coastal Plains include parts of the coastal plain physiographic province not included in the Coastal Flatwoods; and the piedmont area of Maryland, Virginia, North and South Carolina, and Georgia. The land surface is gently rolling to hilly, with elevation variations from tens of feet in the eastern and southern parts of the area to several hundreds of feet in the western and northern parts. Moderately well- to well-drained soils occur in the east and south, and clayey soils are predominant in the west and north. Average annual precipitation ranges from 44 inches in New York and New Jersey to 52 inches in Florida and in other southern-tier States. The growing season averages from about 180 days in the north to 240 days in the south.

Land uses are forests and cash crops with numerous areas of quite large urban-suburban developments.

Eastern Uplands

The Eastern Uplands include all of New England except Cape Cod; the Adirondack, Catskill, Cumberland, Allegheny, Appalachian, Blue Ridge, and Ozark Mountains; and parts of the Appalachian Plateau. The land surface ranges from highly dissected mountains and narrow valleys with relief in thousands of feet to gently undulating hills to relatively level plateaus. Soils are extremely variable, ranging from very thin and in places stony to well-drained sandy soils and rich clay soils. Average annual precipitation ranges from 36 inches to 52 inches, with two unusually high precipitation areas — one of 80 inches near the South Carolina-North Carolina-Georgia border, and one of 74 inches in New Hampshire. The average length of the growing season ranges from 120 days in the north to 210 days in the south.

Mountainous areas are chiefly forested, with small farms in the valleys. However, much of the hilly land is farmed extensively.

Lower Mississippi Valley

Lower Mississippi Valley consists of the broad valley of the Mississippi River, below its confluence with the Ohio River, in the States of Kentucky, Tennessee, Missouri, Arkansas, Mississippi, and Louisiana. The land surface is characteristically quite flat with levee ridges along stream channels 2 to 20 feet higher than adjacent flat back slopes, backwater swamps, and basins. Soils are derived from alluvium and are predominantly sandy and silty in levee ridges and predominantly clayey in the back swamps and basins. Average annual precipitation ranges from 48 to 60 inches. Average length of growing season ranges from 210 days in the north to 300 days in the south. The original vegetation was bottomland hardwoods, but the majority of the land is now given over to farming and related agricultural enterprises.

Corn Belt

Corn Belt includes almost all of Indiana, Illinois, and Iowa, and portions of Ohio, Wisconsin, Minnesota, and Missouri. Land surface over most of the area is relatively flat to moderately rolling hills, with relief generally in tens of feet. The soils in this area are derived from alluvium, deep loess, and drift and are very fertile. Mean annual precipitation ranges from 24 to 44 inches, and the average growing season ranges from 130 to 210 days. The combination of soil and climate make this area one of the outstanding grain-producing regions of the world. The predominant land use is agriculture, with a small percentage of forest. However, this area contains numerous small but intensely developed industrial, urban, and suburban developments.

Lake and Drift Plain

The Lake and Drift Plain is made up of the glaciated northcentral States and includes almost all of Michigan, large parts of Wisconsin and Minnesota, and smaller parts of New York, Indiana, and Ohio.

The land surface over most of the area is composed of gently sloping plains with little relief. Areas around Lake Superior, however, are steeply rolling with considerable relief over short distances. Soils are mainly derived from glacial outwash and range from heavy clay to sand. Average annual precipitation ranges from 24 to 40 inches, and the average growing season ranges from 90 to 180 days.

Poor soils and a short, cool growing season in parts of Minnesota, most of Wisconsin, and northern Michigan impose severe restrictions for agriculture. In these areas, pine forests, bogs, and forage crops predominate. In other parts of the area, agriculture is the predominant land use, with a small percent in forest. Significantly, this area contains the largest number of intensely developed and burgeoning industrial, urban, and suburban areas.

Alaska

Alaska has a varied geographic topography, from coastal plains to rugged, youthful mountains, and a long coastline.

Gravelly, glacially deposited, and finer alluviums and organic soils predominate. Permafrost limits the depth of the root zone. Average annual precipitation ranges from 6 to 100 inches.

The average growing season ranges from 90 to 120 days; however, the almost continuous summer sunlight makes it extremely productive. Agricultural land use is limited and probably will not increase significantly in the next 25 years. Irrigated lands are at altitudes ranging from near sea level to 500 feet, and are small, isolated areas.

Hawaii

Hawaii consists of eight major islands, seven of which are inhabited, characterized by youthful, steep-sloped topography developed in shield-type volcanic cones and lava deposits on which most soil has developed.

Average annual precipitation ranges from 5.7 inches near Kawaihae on the island of Hawaii to 486.1 inches atop Waialeale on Kauai. Generally, the islands' northeastern slopes have high average annual precipitation and the southern coastal areas very low. The growing season extends throughout the year.

Caribbean

The only island having irrigated agriculture is Puerto Rico. It has three topographic areas: (1) relatively flat-lying coastal and alluvial floodplains, (2) gently rolling foothill slopes, and (3) youthful interior mountains.

Soil types are some of the most varied in the world. They vary from tropical to arid, sandy, and free-draining to clayey and poorly draining, and from fertile to barren. The southern part of the island, including foothill and coastal areas, has an average annual precipitation of 30 to 40 inches; the remainder of the island has an average annual precipitation of 70 to 100 inches; and the localized rain forest in the mountainous interior has an average annual precipitation of about 200 inches. The crop growing season generally extends throughout the year.

Agricultural lands which have been traditionally located in the mountain valleys and coastal areas are being displaced by burgeoning urban growth to the foothills area. The mountainous interior is basically in forest, portions of which have been cleared for subsistence farming.

Irrigated Acreage

Table 19 shows the total irrigated acreage in the humid area by characterization areas as obtained from the Technical Work Group Survey. The data show that 78 percent of the irrigated acreage is in the Coastal Plains, Coastal Flatwoods, and Lower Mississippi Valley. Table 20 indicates the major crops grown in the various characterization areas, ranked from top to bottom in decreasing order of magnitude of crop acreage.

Irrigation Methods

Of the approximately 8.5 million irrigated acres, 52 percent is irrigated by sprinklers, 47 percent by surface methods, and 1 percent by drip methods. Most of the surface irrigation is in Florida and the lower Mississippi Valley. Drip irrigation is concentrated primarily in Hawaii, Florida, and Michigan. Sprinkler irrigation is used throughout the area, but predominates in the Eastern Uplands and the Lake and Drift Plain.

Water Sources

In the humid area, 66 percent of irrigation water is supplied by wells, 24 percent by direct stream diversions, and 10 percent by reservoirs. In general, areas of high ground-water use for irrigation correspond to areas with major area aquifers and narrow aquifers related to river valleys (figures 21 and 22). In the Eastern Uplands, aquifers are poor and streams and reservoirs supply 70 percent of the irrigation water.

Table 19.—*Irrigated acreages by States and characterization areas — 1977 (Data obtained from Technical Work Group Survey.)*

Characterization area / States	Coastal Flatwoods	Coastal Plains	Eastern Uplands	Lower Mississippi Valley	Corn Belt	Lake and Drift Plain	TOTAL
Alabama	10,500	49,500					60,000
Alaska							1,445
Arkansas		78,778	11,742	1,419,038			1,509,558
Caribbean area							64,897
Connecticut			15,000				15,000
Delaware	30,000						30,000
Florida	1,735,840	1,340,160					3,076,000
Georgia	75,000	525,000					600,000
Hawaii							179,997
Illinois					68,000		68,000
Indiana			500		2,500	53,000	56,000
Iowa					165,000		165,000
Kentucky			24,750	2,750			27,500
Louisiana	468,572	3,600		87,828			560,000
Massachusetts		6,945	38,355				45,300
Maryland	26,730	6,720	120				32,570
Maine			10,750				10,750
Michigan						338,000	338,000
Minnesota					146,200	240,800	387,000
Mississippi		2,170		213,440			215,610
Missouri			26,300	203,500	79,900		310,200
North Carolina	16,300	140,100	3,900				160,300
New Hampshire			4,800				4,800
New Jersey		89,321					89,321
New York		20,000	11,360			22,720	54,080
Ohio			14,300		27,000	7,000	48,300
Pennsylvania		6,000	21,500			1,200	28,700
Rhode Island			1,500				1,500
South Carolina	15,615	22,450					38,065
Tennessee		1,200	14,000	4,000			19,200
Virginia	8,763	45,927	9,524				64,214
Vermont			1,240				1,240
West Virginia			5,260				5,260
Wisconsin					38,000	214,197	252,197
TOTAL							8,520,004

Practically all irrigation water sources in the humid area are individually developed and owned onfarm systems. The exceptions are the watershed protection and flood prevention projects of the Soil Conservation Service (P.L. 566) that may include irrigation water storage; drainage and irrigation districts; and some Corps of Engineers dams. Individual property owners adjacent to projects are permitted to pump irrigation water from the reservoirs. With the exception of funds provided through P.L. 566 projects, a few Corps of Engineers projects, and some cost sharing assistance through the Agricultural Conservation Program administered by the Agricultural Stabilization and Conservation Service, water supplies have been constructed at the landowner's expense.

Water Quality

In general, quality of water supplies for irrigation is good. There are some problems with saline water in the Coastal Flatwoods, Hawaii, and the Caribbean. Also, some water sources may contain minerals such as iron, sulfur, calcium, and carbonates that could limit the use of water for drip systems.

Table 20.—*Irrigation characteristics.*

Area	Crops[1]	Water source	Irrigation method	Curr. withdrawals of water[1]
Coastal Flatwoods	Vegetables Forage Sugar cane Field crops (corn and soybeans) Orchards, berries Golf courses, flowers, nursery Sod	Ground water[2] — 64% Reservoir — 11% Streams — 25%	Sprinkler — 53% Surface — 46% Drip — 1%	Agriculture Municipal Industrial Recreation and wildlife
Coastal Plains	Field crops (Corn, soybeans, cotton, peanuts, tobacco, small grain, rice) Vegetables Orchards, berries Vineyards Golf courses, flowers, nursery Forage Sod	Ground water[2] — 68% Reservoir — 10% Streams — 25%	Sprinkler — 63% Surface — 37% Drip — 0.1%	Municipal Industrial Agriculture Recreation and wildlife
Eastern Uplands	Field crops (Corn and small grain) Orchards, vineyards Vegetables Forage Golf courses, flowers, nursery	Ground water[2] — 30% Reservoir — 50% Streams — 20%	Sprinkler — 96% Surface — 4% Drip — 0.3%	Municipal Industrial Agriculture Recreation and wildlife
Lower Mississippi Valley	Field crops (Cotton, soybeans, corn, rice) Sugar cane Vegetables Forage Golf courses, flowers, nursery	Ground water[2] — 71% Reservoir —6% Streams — 23%	Sprinkler — 4% Surface — 96% Drip — 0.1%	Agriculture Municipal Industrial Recreation and wildlife
Corn Belt	Field crops (Corn, soybeans, small grain) Vegetables Forage Orchards Golf courses, flowers, nursery	Ground water[2] — 77% Reservoir — 8% Streams — 15%	Sprinkler — 63% Surface — 37% Drip — 0.1%	Municipal Industrial Agriculture Recreation and wildlife
Lake and Drift Plain	Field crops Vegetables Orchards, berries Vineyards Golf courses, flowers, nursery Forage	Ground water[2] — 63% Reservoir — 5% Streams — 32%	Sprinkler — 97% Surface — 0.4% Drip — 3%	Municipal Industrial Agriculture Recreation and wildlife
Hawaii	Sugarcane Pineapple Orchards, berries Vegetables Forage Field crops Flowers, taro	Ground water[2] — 46% Reservoir — 1% Streams — 53%	Sprinkler — 30% Surface — 41% Drip — 29%	Agriculture Domestic
Alaska	Field crops Forage Vegetables	Ground water[2] — 93% Streams — 7%	Sprinkler — 100%	Recreation and wildlife Municipal Hydropower Agriculture
Caribbean	(Not provided)	Ground water[2] — 45% Reservoir — 13% Streams — 42%	Sprinkler — 24% Surface — 76% Drip — 0.2%	Municipal Industrial Agriculture

[1] Ranked in descending order of magnitude.

[2] Pumped wells.

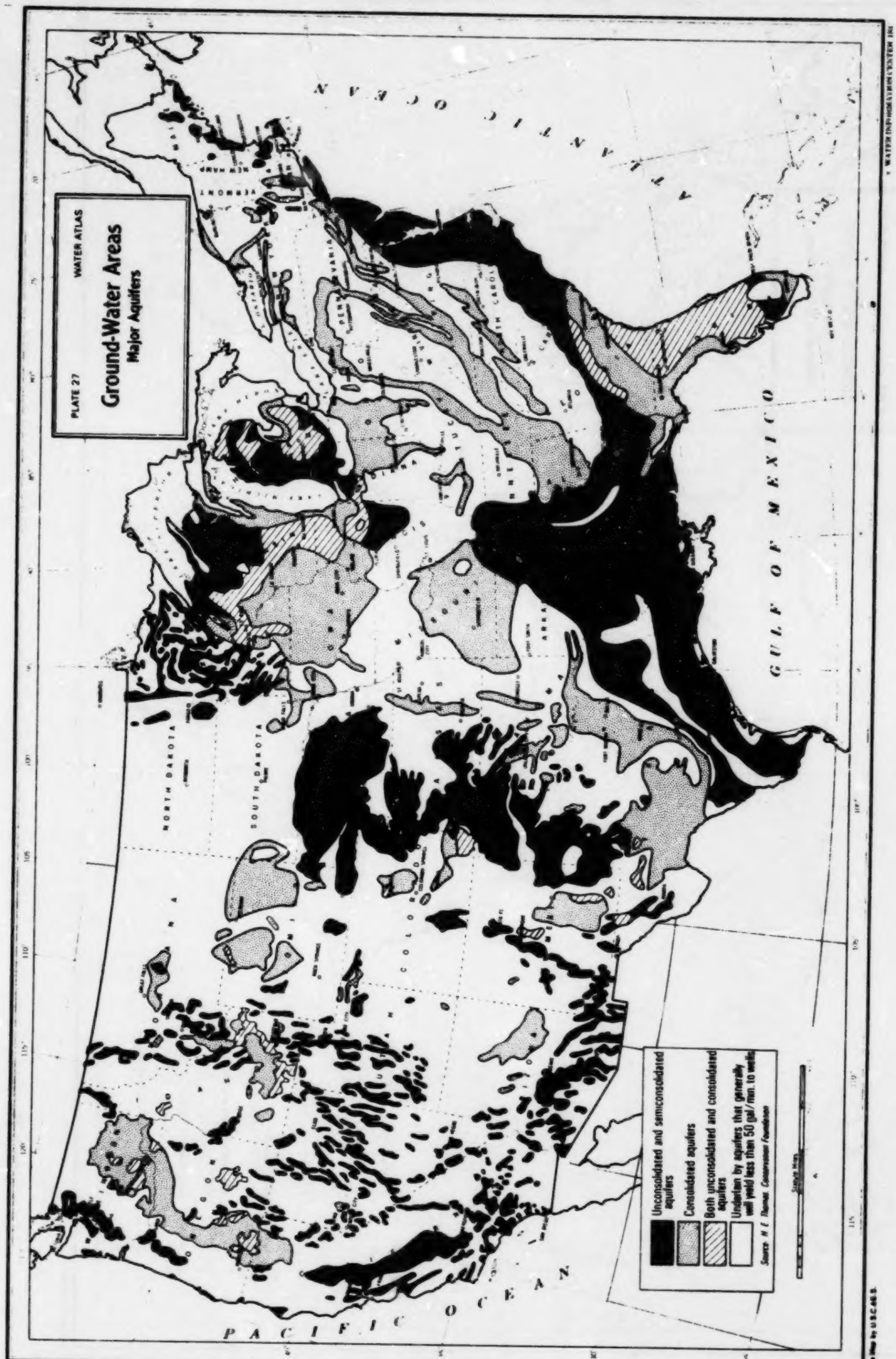
PLATE 27
WATER ATLAS
Ground-Water Areas
Major Aquifers
ATLANTIC OCEAN
GULF OF MEXICO
PACIFIC OCEAN
NORTH DAKOTA
SOUTH DAKOTA
Unconsolidated and semiconsolidated aquifers
Consolidated aquifers
Both unconsolidated and consolidated aquifers
Underlain by aquifers that generally will yield less than 50 gal/min. to wells
Source: H. E. Thomas, Conservation Foundation

Figure 21.—Ground-water areas — major aquifers. (*Source: "Water Atlas," Water Information Center, Inc.*)

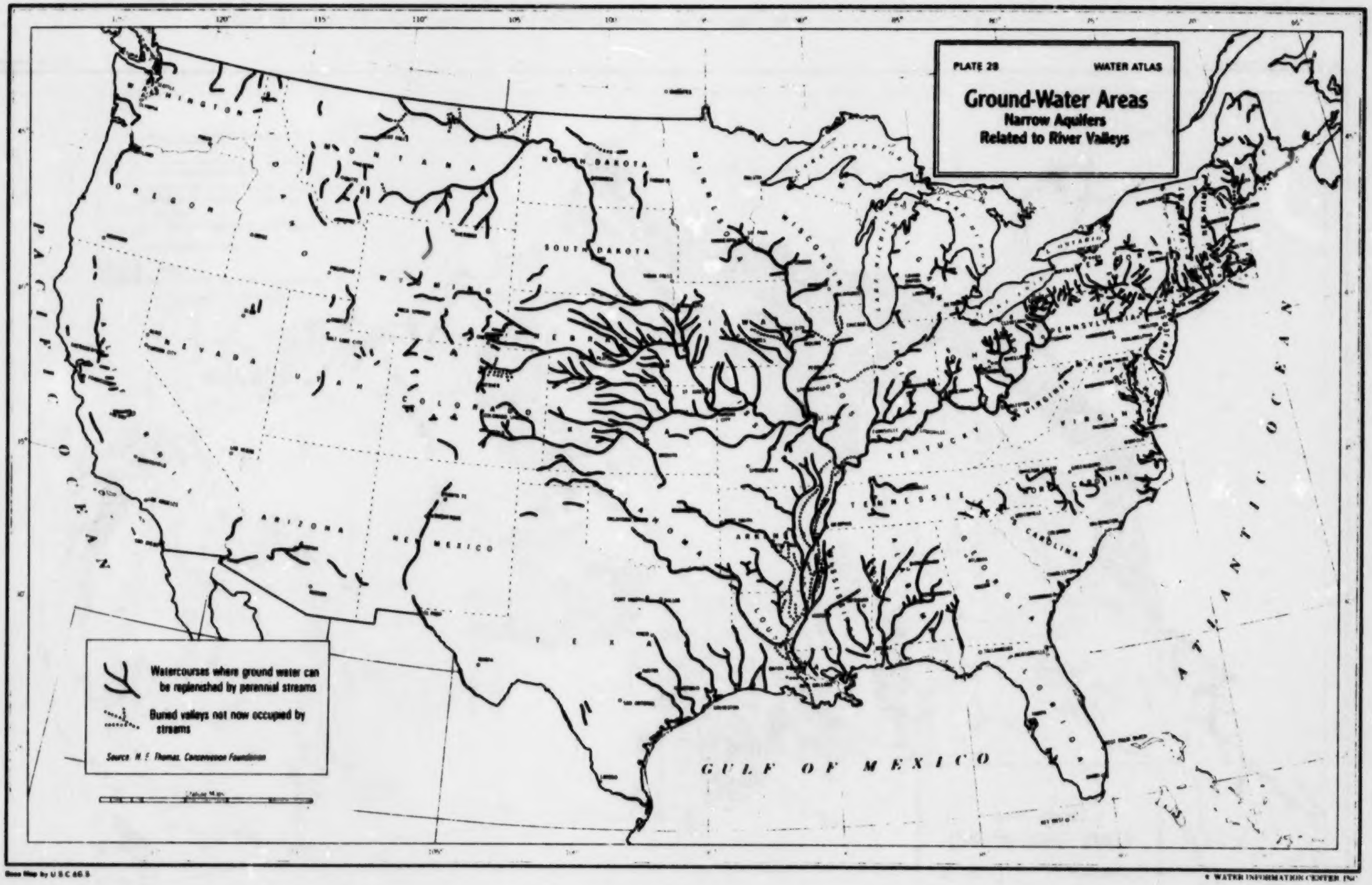
PLATE 28
WATER ATLAS
Ground-Water Areas
Narrow Aquifers
Related to River Valleys
Watercourses where ground water can be replenished by perennial streams
Buried valleys not now occupied by streams
Source: H. E. Thomas, Conservation Foundation
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
WASHINGTON
OREGON
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
NEVADA
COLORADO
ARIZONA
NEW MEXICO
TEXAS
KENTUCKY
TENNESSEE
CAROLINA
Base Map by U.S.C.&G.S.
© WATER INFORMATION CENTER, INC.

Figure 22.—Ground-water areas — narrow aquifers related to river valleys. (*Source: "Water Atlas," Water Information Center, Inc.*)

Competition for Water

In all areas there is some competition for water withdrawals. The current withdrawals in each area ranked in descending order of magnitude are shown in table 20. Excessive withdrawals cause saltwater intrusion in some coastal areas. Also, withdrawals for one use may adversely affect other users. These items are discussed in the problems section of this chapter.

Except for Florida and Mississippi which operate under a permit system similar to the Doctrine of Prior Appropriation, surface water is controlled primarily by the Riparian Rights Doctrine.[1] Generally, a permit to pump is not necessary, but some States require a permit for riparian users.

Thirteen States have a permit system for ground water. This varies from requiring a permit to drill a well to limiting the quantity of water that can be withdrawn. North Carolina has designated certain areas as capacity use areas in which a permit is required to drill a well, the quantity of withdrawal is limited, and the quantity of surface water withdrawal may be limited.

Irrigation Water Use

The annual amount of irrigation water normally applied to crops in the respective States during an average rainfall year was reported. The crops were categorized into field and forage crops, vegetables, orchards, berries and vineyards, sugar cane, and sod. Some other crops were reported, such as nursery stock, tobacco, golf course and municipal turf, taro, and sunflowers. Approximately one million acres of golf courses and municipal turf are irrigated, of which 900,000 acres are in Florida. (Figure 23.)

Efficiency

The States provided data on the efficiency of existing delivery and application systems. Delivery systems are defined as those portions that transport water from the source to the edge of the field to be irrigated, and application systems are defined as those portions that convey water from the edge of the field to the crop. Data were also provided on improving the efficiencies of both delivery and application systems, by acres and percentages. The efficiency of delivery could be improved by an average of approximately 20 percent on 2.3 million irrigated acres, and the application efficiencies could be improved by an average of approximately 20 percent on 2.9 million acres.

As has been previously outlined, open channel conveyances (mostly in Arkansas, Florida, and the Caribbean) lose significant quantities of water to evaporation and seepage (in the humid area there are few offsite impacts). Consequently, the two most often mentioned methods needed to improve delivery efficiencies were lining of existing canals and conversion from canals to pipelines. Better management and design, conversion to low-volume systems, and tailwater recovery were the most often cited methods for improving application efficiencies.

Sprinkler irrigation efficiencies reported in the Technical Work Group Survey ranged from 50 to 85 percent and averaged 71 percent; surface irrigation efficiencies ranged from 30 to 65 percent and averaged 53 percent; and drip irrigation efficiencies ranged from 75 to 95 percent and averaged 88 percent. Since little research or evaluation work has been done in the humid area to determine onfarm efficiency, stated efficiencies are estimates.

Irrigation Water Management

Irrigation Water Management (IWM) was defined for the survey as the scheduling of irrigation water application based on the factors of existing soil moisture conditions and the consumptive use rate of the crop. Improved IWM can reduce water withdrawals, thus reducing energy use. The States reported 1.6 million acres of irrigated cropland on which some form of IWM is practiced. It was further reported that there are 6.1 million acres upon which better IWM is needed. The latter figure

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[1] Several other States have permit systems which operate in conjunction with riparian rights.

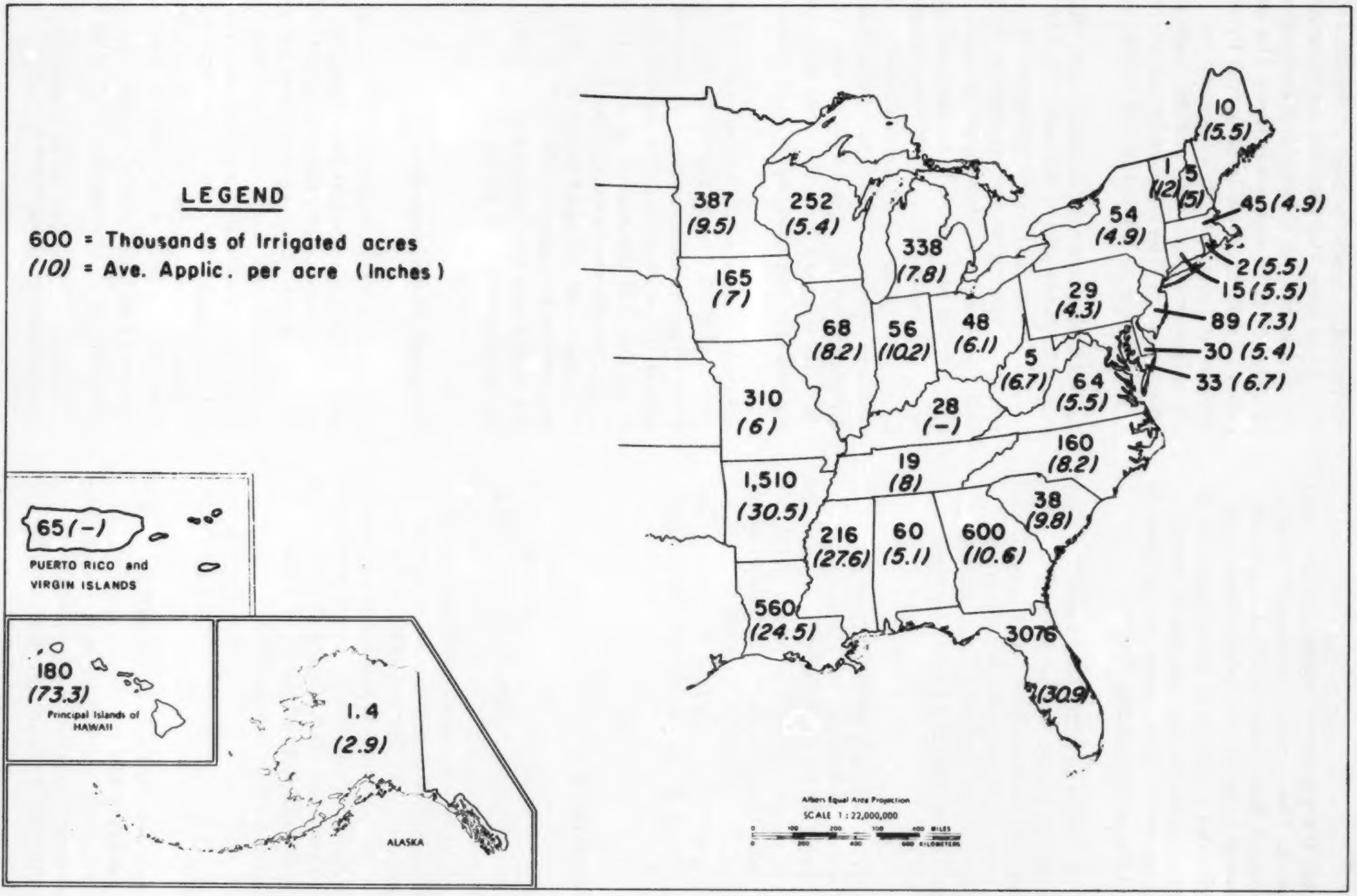

LEGEND
600 = Thousands of Irrigated acres
(10) = Ave. Applic. per acre (Inches)
387 (9.5)
252 (5.4)
338 (7.8)
54 (4.9)
10 (5.5)
1 (12)
5 (5)
45 (4.9)
2 (5.5)
15 (5.5)
89 (7.3)
30 (5.4)
33 (6.7)
165 (7)
68 (8.2)
56 (10.2)
48 (6.1)
29 (4.3)
5 (6.7)
64 (5.5)
310 (6)
28 (–)
160 (8.2)
19 (8)
1,510 (30.5)
216 (27.6)
60 (5.1)
600 (10.6)
38 (9.8)
560 (24.5)
3076 (30.9)
65 (–)
PUERTO RICO and VIRGIN ISLANDS
180 (73.3)
Principal Islands of HAWAII
1.4 (2.9)
ALASKA
Albers Equal Area Projection
SCALE 1 : 22,000,000

Figure 23.—Irrigated acreage — average application.

represents 69 percent of the total irrigated acreage in the humid area. Federal and State technical assistance is needed in the form of onsite planning and through research and demonstration projects to show the irrigator the water conservation benefit of irrigation water management.

Trends and Problems and Amelioration Methods

Irrigated Acreage

Irrigated acreage will continue to increase, particularly in the Lower Coastal Plains, Coastal Flatwoods, and Corn Belt. The opinion of those responding to the survey indicated that over 24 million acres of existing farmland could be irrigated and almost 10 million acres should be irrigated to maximize production. It was further indicated by the respondents that in excess of 14 million acres (exclusive of Alaska which reported 18,500,000 acres) potentially could be converted from other land uses to cropland production by the year 2000, of which 16 percent might be irrigated, principally by sprinkler. However, some of the reported acreage that would benefit from irrigation will, not be irrigated because of inadequate water supply or high water source development costs.

Irrigation Methods and Water Sources

The predominant method of irrigating additional acreage may be sprinkler, with surface and drip methods being rather evenly ranked behind sprinklers. If irrigation acreage continues to increase as projected, new water supplies must be developed to meet the increased demands. In the 31 eastern States, water for new irrigation is expected to be obtained equally from surface and ground-water sources. However, on the characterization area basis, the water sources are expected to be distributed as shown on table 21.

Table 21. — *Estimated changes in percent of irrigation water withdrawal between 1977 and 2000.*

Characterization Area	Source Ground Water		Surface Water	
	1977	2000	1977	2000
Coastal Flatwoods	64	49	36	51
Coastal Piains	66	42	34	58
Eastern Uplands	30	31	70	69
Lower Mississippi Valley	71	55	29	45
Corn Belt	77	67	23	33
Lake and Drift Area	63	75	37	25
Alaska	93	90	7	10
Hawaii	46	50	54	50
Caribbean	—*	45	—*	55

*Not reported.

Total water withdrawals from all sources are expected to increase, but there may be a significant shift from ground water to surface water sources in the Coastal Flatwoods, Coastal Plains, Lower Mississippi Valley, and Corn Belt. This shift would be due in part to the decline of ground water levels in localized areas.

Surface runoff is sufficient to provide large quantities of surface water storage that could be developed to meet the needs of irrigation and other uses. Surface water sources will be developed primarily offstream in the Coastal Flatwoods and the lower Mississippi Valley and equally distributed between offstream and onstream uses in the Coastal Plains and the Corn Belt. (Figure 24)

In some areas, adequately treated municipal wastewater could be considered as a source of additional water supply for irrigation, resulting in increased crop production and a disposal source for municipal waste water.

Competition for Water

In certain areas, increased withdrawals and attendant consumptive use of water for irrigation contributes to decreased streamflows, thus limiting downstream uses and increasing the competition for water by all users. The problem is further intensified by the increasing demand for nonagricultural withdrawals and instream uses. Since irrigated agriculture must compete with all other uses, this competition could result in a decrease in water available for irrigation. Thus, irrigators will be forced to make better use of available water. This might include more efficient methods of irrigating and improved water management.

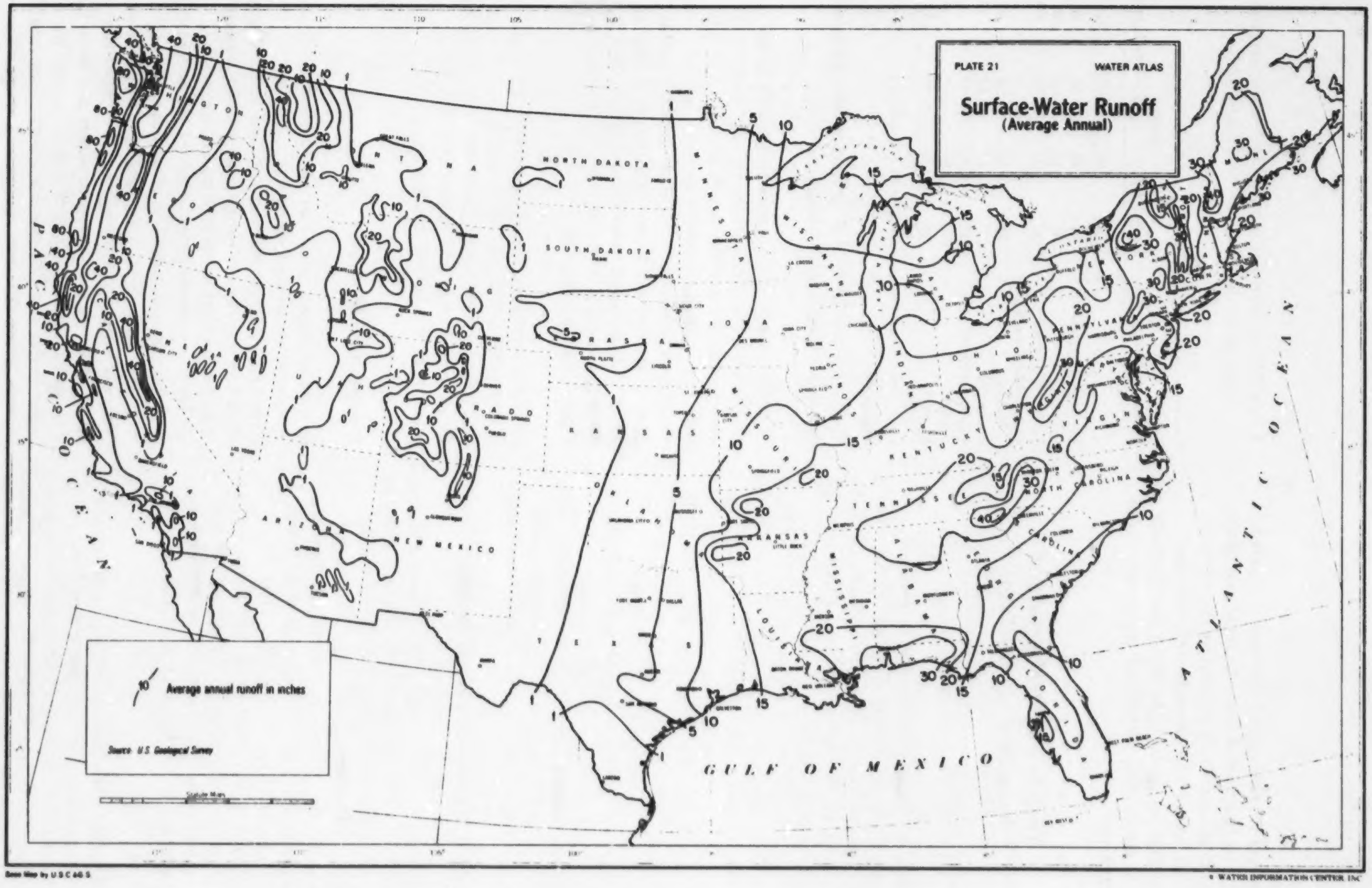


PLATE 21
WATER ATLAS
Surface-Water Runoff
(Average Annual)
Average annual runoff in inches
Source: U.S. Geological Survey
Statute Miles
NORTH DAKOTA
SOUTH DAKOTA
NEW MEXICO
GULF OF MEXICO
ATLANTIC OCEAN
PACIFIC OCEAN
Base Map by U.S.C.&G.S.
© WATER INFORMATION CENTER, INC.

Figure 24.—Surface-water runoff — average annual. (*Source: "Water Atlas," Water Information Center, Inc.*)

Energy Usage

Since sprinkler irrigation is practiced on 52 percent of the irrigated acreage in the humid area, the demand on energy sources is relatively high. And because use of sprinklers is expected to increase in the future, the consumption of energy will continue to be high. Broad-scale conversion to low-pressure, low-volume systems, though reducing energy use, will likely be uneconomical for the irrigator. Any conversion from surface systems to sprinkler systems will result in increased energy consumption. Therefore, an increase in overall energy consumption is to be expected in the future.

Nineteen States indicated an increase in the use of diesel fuel, while only 10 indicated an increase in both diesel and electric power. The remainder indicated a decrease in both gasoline and gas. These trends indicate an ever-increasing dependence upon diesel fuel as a source of energy.

In answer to the question "Is the cost of energy causing farmers to discontinue irrigation, reduce quantity of water applied, and defer installation of irrigation systems?" nearly all replied "No." This suggests that the humid area farmer has confidence that abundant energy sources will continue to be available and that irrigation as a production tool in farming is necessary.

The survey showed that 50 to 60 percent of the irrigation farmers are looking for ways to become more efficient and to better manage their systems, indicating that many are now doing a good job with the available technology, but that additional assistance is needed.

The survey further indicated that only 20 percent have discontinued irrigating lower value crops due to high energy costs, which reflects the view that they are only irrigating crops that are necessary to irrigate.

Diesel fuel requires fewer gallons per brake-horsepower hour. Because it is less in demand and more competitive in price, the humid area farmer is making perhaps the best energy management decision in spite of the power units' higher initial costs.

Technology

The lack of a consistent labor force is a major reason irrigation farmers are purchasing mechanical move systems such as center-pivot, self-propelled gun, booms, and side-roll sprinklers. Mechanical move systems also allow for better and more flexible farm management. Consequently, it is expected that the trend in the installation of the mechanical move systems will continue.

Low-volume, low-pressure systems also can have low labor requirements and provide for good farm management and flexibility, but the installation costs are often high. Clogging of application systems by algae growth, bacterial activities, and solids that are either precipitates or that are introduced to the system from the water source can be a major operation and maintenance problem. Approximately 170,000 acres are predicted to be converted to low-volume systems from surface and sprinkler systems. However, conversion to low-volume systems might not be economically feasible for the irrigator unless high value crops are involved.

There are a variety of scheduling methods available; all rely on accounting for the moisture balance in the system. Some rely entirely on the onsite measurement of soil moisture, while others rely on weather factors. Onsite soil moisture measurements can be taken by a variety of equipment that ranges from the relatively inexpensive tensiometer to the more sophisticated neutron probe. Because of the multitude of methods and equipment, the farmer can be confused as to what can be relied upon. Consequently, the farmer often elects to use none of the available methods or equipment, but instead uses his experience to decide when irrigation should begin. This method of scheduling can result in improper water application quantities, and without technical guidance will probably continue to occur.

The survey indicated that two of the irrigation farmer's most critical future needs are in the areas of technical assistance and new technology. Additional technical assistance that could be provided by Federal and State agencies would satisfy much of the need for better and more timely irrigation water scheduling. However, due to budgetary constraints and lack of personnel in the agencies, the current low level of technical assistance will not improve without a major change in agency programs and goals.

New technology is being developed but, because of the rapidity of its development, problems have occurred that were not foreseen. The corner center-pivot systems have, in many cases, eliminated major problems of irrigating the corner wedges of square and rectangular fields, but the large volume end guns can be inefficient and cause erosion. Drip irrigation holds promise of being a major water conservation practice but, as previously stated, the systems can be expensive to install and have operation and maintenance problems. Low-pressure systems, mainly with center-pivot systems, offer rapid water application rates with low power expenditures, but they apply water at such high rates that excessive runoff can cause erosion problems and wastage of irrigation water.

Quality of Water for Increased Irrigation

Quality of water will remain adequate for most crops, even with the projected increases, with two exceptions:

1. As withdrawals for irrigation consumptive use increase in areas adjacent to salty or brackish water, the quality of the withdrawn water may be poor due to the intrusion of salty water into ground-water aquifers. Such degradation also will affect withdrawal for nonagricultural uses. Better water management, the use of suitable irrigation techniques, water allocation, and the use of treated municipal wastewater are methods that can be employed to curtail the intrusion of poor quality water into freshwater aquifers. Research could develop improved techniques to recharge aquifers with water of acceptable quality.

2. In areas that are satisfactorily surface irrigated with water containing high levels of dissolved solids, a change in method to sprinkler or drip irrigation may preclude the use of this water. Some crops presently being irrigated will be affected by the dissolved minerals, such as the spotting of tobacco leaves by dissolved iron. Other crops which are not salt-tolerant may not be able to grow well in the presence of salty or brackish water. Additionally, water containing high levels of dissolved solids could clog the orifices of low pressure drip-irrigation systems, causing an extensive maintenance problem. Growing the proper crop and using the correct application method for the water quality available can help overcome poor water quality problems.

Effects of Irrigation on the Environment and Water Quality

Increased consumptive use for expanded irrigation would intensify the problems related to the reduction of freshwater inflow to estuaries. Such increased consumption would reduce streamflow during periods of natural low flow, adversely affecting instream beneficial uses such as for aquatic life, recreation, and water quality needs. However, existing irrigation practices in the humid area have generally had minor impacts on the environment and water quality, with the following exceptions:

1. Saltwater intrusion into fresh surface and ground waters in coastal areas, caused in part by withdrawals for irrigation, has contributed to water quality degradation for public supply and other uses. This problem is noteworthy in Long Island, New York; Florida; and Hawaii. Reduction of freshwater inflow to some estuaries, particularly in Hawaii and southern Florida, caused in part by irrigation withdrawals, has adversely affected estuarine fish and wildlife habitat. Allocation of water, the use of treated municipal wastewater for crop irrigation and other uses, such as fish and wildlife and ground-water injection, could offset some of the adverse effects of saltwater intrusion. However, these uses must not endanger drinking water supplies.

2. Water drained from agricultural lands, both irrigated and nonirrigated, in Florida and other States where sandy and other permeable type soils exist, can contain fertilizer and pesticides.

Studies at the University of Florida have shown that significant quantities of nitrates and phosphates occur in drainage waters collected in subsurface drain systems. Tailwater recovery and pumpback systems could reduce the impacts of this problem.

3. Clearing of borders, fence rows, and adjoining wooded areas to facilitate the use of self-propelled center-pivot and mechanical move systems designed for large acreage irrigation has accented environmental problems. Drainage of wetlands and clearing of bottomland hardwoods to facilitate agriculture (both irrigated and nonirrigated) has reduced habitat for certain species of fish and wildlife, some of which are listed as endangered. Such an adverse impact is significant in the Lake and Drift Plain, Lower Mississippi Valley, and particularly in the Coastal Flatwoods area. Technical assistance by Federal and State agencies could be used to curtail impacts on fish and wildlife through a coordinated program of education, information, and onsite planning assistance.

4. Due to the expanding market for agricultural products, erodible, marginally productive land is being cleared for agriculture, often requiring that it be irrigated to be profitable. Sediment, nutrient, and pesticide pollution of the receiving waters sometimes occurs. Existing cost-share programs do not provide sufficient incentive for farmers to install erosion control practices. Additionally, the economic benefits of erosion control practices and features are not always recognized. Increased technical assistance by Federal and State agencies would provide for planning and implementation of long-range protection of the soil resource and the immediate effects of protecting offsite water quality. Cost-sharing by governmental agencies would stimulate added interest in erosion control measures. It is generally believed that water discharged from rice fields in the Lower Mississippi Valley contains quantities of fertilizers and pesticides that create undesirable impacts on the receiving waters. However, there is little conclusive evidence to support this theory. Louisiana, although recognizing that fertilizers and pesticides probably do get into State waters from rice fields, did not identify any resultant problems. Arkansas reported research that showed a net reduction in the nitrogen and phosphorus content of the water between the point of entry to rice fields and the point of discharge. No pesticide data were reported. Tailwater recovery and pump back systems can be used to mitigate any problems that might arise.

Social, Legal, and Institutional

Irrigation creates one of the many demands on the present water resources. Closely spaced wells can affect each other by the drawdown imposed during heavy irrigating periods. Streamflows may be adversely affected by heavy withdrawal, especially since withdrawal for irrigation is normally done during periods of low streamflow. Assuming the trend for ever-increasing irrigation in the humid area continues, the impact on ground water and streamflows will increase and will effect a much greater awareness by the public. The conflicts regarding water use will become more severe.

Since a majority of the States in the humid area do not have definitive laws regarding water rights, serious legal questions can and do evolve regarding an individual's right to unlimited withdrawal from ground water or from streams. Any States faced with declining ground-water tables will have to make decisions regarding development of alternative sources of water (such as reservoirs or interbasin transfer) or legislative controls on the usage of ground water. Consequently, as water use increases, water laws need to be developed that provide for beneficial uses, equitable allocation of water, and water use priorities.

All sectors of the economy — municipal, industrial, and agricultural — are using water at an ever-accelerating rate. These are characterized by more and more water shortage problems throughout the humid area. In the absence of water rights statutes (only 13 States require water use permits) which define priority use and/or allocation procedures, the nonpermit States do not have regulatory agencies charged with policing water usage.

Monetary

Expenditures for irrigation systems are quite high. If a landowner chooses center-pivot sprinkler irrigation, he is faced with first costs of $40,000 to $50,000 for a system covering approximately 135 acres. Energy costs can run from $1.50 to $2.50 per acre-inch of water applied by sprinklers.

Where reservoir storage is involved, the costs of impoundments and delivery systems can become prohibitive for the individual landowner. Only through water management districts, cooperatives, special-purpose districts, and other governmental units can the costs be reduced to the individual landowner.

Energy and equipment costs will continue to rise. Only through production increases and higher crop prices will the farmer be able to afford irrigation. To meet future demands for food and fiber and to stabilize food prices, public financial support for off-farm reservoirs and delivery systems will be needed to provide the stimulus for proper development of the soil and water resources. Also, assistance to the farmer in the planning, design, and installation of onfarm irrigation systems will help assure the appropriate and efficient use of water supplies and other resources.

Chapter 7

Approaches to Implementing Water Conservation Programs in Irrigated Agriculture

Better irrigation water use and management offers opportunities to achieve a wide array of benefits from available water supplies. The preceding chapters describe the history, present status, and some measure of the diversity that exists in the practice of irrigation, particularly in the western States. They also discuss the kinds of measures needed to improve the use and management of water in irrigated agriculture, along with the results of some studies which show the general costs, effectiveness, and impacts of areawide programs (Soil Conservation Service) or for a group of existing irrigation projects (Bureau of Reclamation and Bureau of Indian Affairs). While this information is useful in understanding the overall opportunities and effects of conservation programs, consideration of the most effective measures and means for determining problem areas and programs is needed. Because of the diversity that exists in the practice of irrigation and the high total cost of implementing a complete and comprehensive program, priorities should be set on Federal, State, and local actions.

Individual irrigators and irrigation districts are currently implementing measures to improve the effectiveness of water used for irrigation. A projection of the effectiveness of ongoing programs is shown in table 14 as the 25-year trend. Private industry, with assistance from Federal and State programs, is contributing to the accomplishments. Current priorities are based on the needs of the individuals and districts to solve existing problems in irrigation water use and management. The degree of emphasis placed on water conservation through assistance programs, of course, influences these priorities. However, the current incentive for farmers appears to be tied to the farm economic situation which reflects rising costs of energy and labor as well as the production losses associated with water shortages or excess application of available water.

Irrigation districts and companies are giving priority to improving the dependability of water supplies and to improving and maintaining conveyance systems to better meet the needs of the water users in their districts. The increases in costs which must be passed on to the water users are certainly important factors in determining district programs for water conservation or other purposes. A major water conservation objective of irrigators and local water districts has been to maintain a dependable water supply so that long-range investments in improved conveyance and onfarm irrigation measures can be justified. Concern for water conservation has been the greatest where ground-water depletion is recognized as a long-range problem, where existing surface supplies are inadequate without careful management, and where costs for water delivery or pumping have a major impact on production decisions.

In addition to the onsite benefits which have been the major incentive for water conservation measures, current national concerns about water quality, instream flow conditions, and depletion of ground-water aquifers require that future actions give consideration to these offsite and general public benefits. New approaches are needed in identifying problem areas, selecting solutions which give balanced consideration to onsite and offsite effects, and determining priority for Federal and State programs.

The President's water policy directives of July 12, 1978, clearly recognize the necessity of implementing water conservation programs. While the directives focus on the responsibilities of Federal agencies to encourage water conservation as an objective of their existing programs, the directives also recognize the States have the primary authority and responsibility for water management. Therefore, the President is proposing to provide $25 million annually in matching grant assistance to States implementing water conservation technical assistance programs.

Under this water policy, water conservation becomes a basic consideration in all Federal and federally assisted programs. In those programs which affect irrigated agriculture, the issue is not whether water conservation should be pursued, but what water conservation actions will be most effective in meeting the long-range economic, social, and environmental goals of society. A process for planning and implementing water conservation programs for all purposes which will provide these assurances is needed. In the western States, successful water conservation programs must include irrigation water use and management as their major concern.

Although irrigation is by far the major consumptive water use in the West and is increasing in the East, there are other uses that must be considered. Demands for water for these uses are also increasing in response to a growing human population and a perceived need for greater energy independence. The consumptive water use for such purposes will of necessity affect irrigation use. At the same time, the public is increasingly seeking protection for water quality and instream values such as fish and wildlife, recreation, and aesthetics. Other instream uses with acknowledged economic benefits include navigation, hydropower generation, and waste assimilation. Conserving water offers potential relief from some of the mounting pressures of competing uses.

The trend in water planning appears to be toward greater multiple-purpose use of reservoir storage, toward greater State leadership in water use planning and enforcement, and toward increasing protection for all environmental values.

A Process for Planning and Implementing Water Conservation

In order to achieve better coordination among Federal programs and among the Federal, State, and local levels of government, a positive and concerted effort is needed. To be successful there must be a commitment at all levels of government as well as throughout society that water conservation is an integral part of a successful long-range national water and related land resource program. Such a program must recognize previously mentioned trends and be focused sharply on equitable and attainable objectives.

To achieve such a coordinated program, State governments should take the lead in the development and coordination of water conservation programs in the State for all water use sectors. Activities of this type are currently underway in some States. All Federal, State, and local organizations should be a part of this coordinated effort. Such a program might be termed a *Cooperative Water Conservation Program.* Federal grants, as necessary, should be made available to the States to bring about the coordinated water conservation programs at the earliest possible time. Priority should be given to those States where water use has a major impact on the surface and ground-water supply, water quality, instream flows, and economic stability.

Saving water for conservation's sake alone is a questionable goal. Before Federal investment in any water conservation program is implemented, the objectives to be served should be clearly defined. Some objectives identified by this study which merit consideration include:

1. Improving farm income through higher crop yields and reduced production costs.

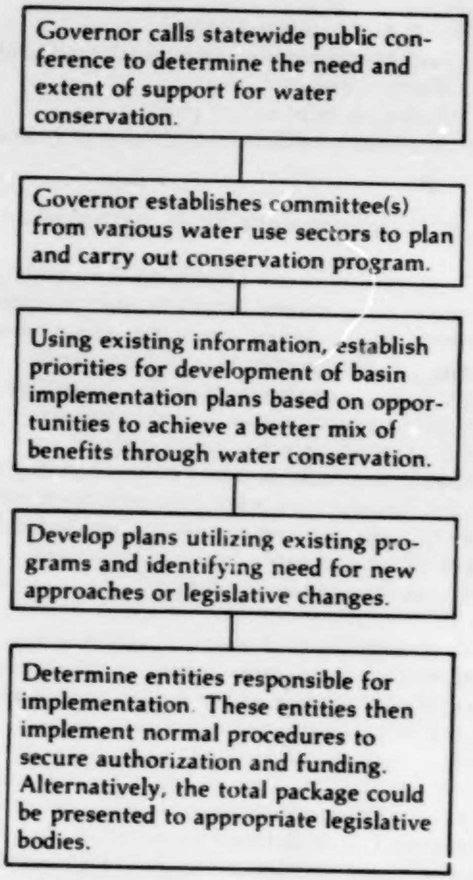
2. Firming up water supplies for junior appropriators.

3. Improving instream flow conditions.

4. Attaining point and nonpoint source pollution control goals.

5. Improving estuary conditions.

The major steps in implementing a *Cooperative Water Conservation Program* in a State are sketched as follows:



Governor calls statewide public conference to determine the need and extent of support for water conservation.

Governor establishes committee(s) from various water use sectors to plan and carry out conservation program.

Using existing information, establish priorities for development of basin implementation plans based on opportunities to achieve a better mix of benefits through water conservation.

Develop plans utilizing existing programs and identifying need for new approaches or legislative changes.

Determine entities responsible for implementation. These entities then implement normal procedures to secure authorization and funding. Alternatively, the total package could be presented to appropriate legislative bodies.

The statewide conference is needed to set forth the apparent short- and long-range problems as viewed by responsible people and to determine interest in pursuing solutions. Support for action programs must be evident not only by those who stand to benefit, but also by those who will be responsible for carrying out improvement measures.

To carry forth with the *Cooperative Water Conservation Program* following the conference, the Governor could establish a committee on irrigation water use and management to plan and carry out that portion of the water conservation program. This committee would consist of representatives of appropriate State and Federal agencies, irrigation and conservation districts, farmers, industry, and public interest groups. Assistance available from existing Federal and State programs could be identified and matched with priority activities. Need for new initiatives or programs could be identified in this manner also.

Because of the site-specific nature of water and other resource problems, the statewide water conservation program would need to provide for an evaluation of each of the State's hydrologic sub-units separately. This is essential to determine the existing water supply and use, the need for additional water, instream flow conditions, water quality, ground-water conditions, and water management problems in project areas and on farms. Some of this information is currently available in many States and can be supplemented to set priorities for new measures and programs. Those programs and entities having the most to offer in each basin would be identified in the implementation plan.

Procedures for Establishing Priorities for Water Conservation Needs by State Hydrologic Sub-units

A procedure for evaluating and establishing priorities for the most urgent water conservation needs in a State is required for effective and realistic programing. Not all areas of the country need equal attention in water conservation. A means of identifying the most critical areas, determining the opportunities for solutions through water conservation programs, and setting forth a reasonable and acceptable program should be developed before major new water conservation initiatives are undertaken at the Federal or State levels.

Planning for effective water conservation cannot be separated from comprehensive water and related land resource planning as accomplished through development of State water plans or cooperative Federal-State plans. However, because much water and related land resource planning has been carried out, data are available on which to establish priorities for future water conservation efforts. The following outline specifies those items which should be considered in the evaluation procedure.

Items to be Considered in Evaluating Irrigation Water Conservation by Hydrologic Sub-units within Each State[1]

1. Supply and condition of water and related resources:
    a. Surface water — availability, use, quality.
    b. Ground water — availability, use, quality.
    c. Irrigated areas — amount, productivity.
    d. Wildlife habitat associated with irrigated areas — kinds, amount, conditions, importance.
    e. Instream flow — critical reaches, and flow needs.
    f. Water storage system — adequacy and flexibility.
2. Irrigation water use and management:
    a. Water management problems and treatment potential.
    b. Conveyance system problems and treatment potential.
    c. Onfarm system problems and treatment potential.
3. Needs for increases in quantity and quality of water supplies:
    a. Nonagricultural withdrawals -- municipal, energy.
    b. Instream flow needs — amounts and seasonal aspects.
    c. Agricultural water shortages — annual, seasonal.
    d. Water quality standards — point and non-point treatment areas.
4. Institutional setting:
    a. Status of water appropriation — over-appropriated or other situations.
    b. Status of State water law — recognizes and protects instream uses, incentives for users to conserve water.
    c. Irrigation districts and other water user organizations — adequacy and flexibility to achieve a best mix of benefit and shared risk.
5. Potential impact of water conservation:
    a. Economic benefits and costs — onsite, offsite.
    b. Environmental — onsite, offsite.
    c. Energy requirements.
    d. Long-term effects on water availability.
6. Potential for implementation:
    a. Institutional and environmental constraints.
    b. Benefit-cost justification.
    c. Financing (private and public).
    d. Availability of Federal and State programs.

Considerations for Plan Formulation

Once priority areas are established for carrying out water conservation programs and measures, the development of implementation plans must be based on sound principles and standards. Major public investments to improve existing irrigation systems require a comprehensive, interdisciplinary analysis showing that better utilization and management of the water is needed, feasible, and consistent with State water plans and water rights procedures and Federal policy relative to public benefit of improved instream flow and water quality.

In evaluating the potential for implementing irrigation system improvements, consideration must be given to the entire project area served by the water supply and conveyance system. Each project should be analyzed as to its impact on basinwide hydrology and resource use and quality. Analyses of reorganization or resizing of conveyance systems must consider onfarm system changes and water application requirements. Changes or major improvements in off-farm and onfarm systems need to be jointly analyzed and evaluated so that each can be managed efficiently. The relation of diversions, canal seepage, and operational spills to local wildlife habitat, instream flows, water quality, and ground-water recharge will be determined.

Means for determining those measures best suited for implementation in any given area currently exist. However, questions relative to the cumulative effect of the widespread installation of onfarm measures are more difficult to answer. Future programs of assistance in the implementation of onfarm measures should not only provide for solution of onsite problems and benefits, but also should provide for evaluation of downstream and offsite effects. In areas where water quality and instream flow, or water supply problems are not significant, irrigation water conservation programs and measures should be geared primarily to meet the needs of the individual landowner. However, where offsite problems do exist, specific studies should be carried out to identify the magnitude of such problems and the extent to which they can be solved or will be modified with implementation of alternative onfarm measures. (Section 208 of the Clean Water Act, salinity control acts, and instream flow studies should be used.) Priority for selection of areas for assistance in the implementation of onfarm measures should be based on these findings as well as the onfarm or onsite benefits.

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[1] The hydrologic unit maps for each State published by the Water Resources Council and distributed by the U.S. Geological Survey should be used.

The President's water policy statements of June 6, 1978, directed the Federal agencies to seek increased State cooperation in protection of instream flows and ground-water resources. Although not specifically stated, there is implication in the policy statements that water conservation can help provide for this protection. To the extent feasible, *Cooperative Water Conservation Programs* should provide for an assessment of ground-water and instream flow protection needs and the opportunities to help meet these needs through implementation plans for water conservation.

Certainly, major improvements in irrigation systems have the potential for (1) modification in streamflow patterns in some stream reaches, (2) reduction in ground-water withdrawals, (3) reduction in ground-water recharge in certain areas, and (4) improvements in water quality. However, the effects are quite site-specific, and generalizations about the relation of irrigation efficiencies to instream values, ground-water aquifers, and water quality can lead to erroneous conclusions and possibly costly and ineffective actions.

As a result of the varied relation between irrigation water conservation and protection of ground-water aquifers, instream flows, and water quality, a general prescription of recommended actions is not possible. However, specific actions are appropriate under given conditions or situations and should be considered in the development of the *Cooperative Water Conservation Programs.* Examples of these are presented in table 22. To further improve irrigation scheduling programs, new equipment needs to be developed to measure soil water content with minimum management effort. Better techniques are needed to improve the estimate of rainfall, plant growth, production, and evapotranspiration so better management decisions can be made where water supplies or system capacity limit irrigations. Optimum scheduling methods vary with climatic condition, soil type, irrigation method, crop, and source of water supply. Thus, many alternatives need to be studied to determine the best techniques for each irrigated area. Adoption of improved water management practices could be greatly facilitated through educational programs.

Research

Ongoing research on reducing crop consumptive use by stressing the crop during noncritical growth stages shows considerable promise. For example, studies in several western States[2] [3] [4] show that there is promise for water savings with only minor reductions in yield of corn grain when water stresses are imposed at selected times in the life cycle. Such research needs to be extended to develop techniques to produce these stresses, under a variety of climatic and soil conditions, with a high degree of assurance that yields will not decrease.

Systems need to be developed, especially for surface irrigation, that integrate knowledge of irrigation water management, automation, and water measurement. Such systems would simplify or reduce the number of management decisions to be made by the farmer for efficient water application and provide low energy surface methods with some of the labor-saving attractiveness of sprinkler and drip irrigation.

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[2] "Irrigating Corn with Limited Water," Proceedings from Irrigation Short Course, G. Dennis Wilson, Darrell G. Watts and Paul E. Fischbach, Department of Agricultural Engineering, University of Nebraska, Lincoln, January 1978.

[3] "Optimizing Crop Production through Control of Water and Salinity Levels in the Soil," Utah Water Research Laboratory, College of Engineering, Utah State University, Logan, September 1977, PRWG151-1.

[4] Proceedings of the American Society of Civil Engineers, Irrigation and Drainage Division Specialty Conference on Water Management for Irrigation and Drainage, Reno, Nevada, 1977.

Table 22.—*Scenarios illustrating site-specific conditions for water conservation programs.*

Condition or Situation

Scenario 1.

- Irrigation occurs in high mountains, intermediate valleys and on plains.
- Water supply is direct diversion in high mountains, both from surface storage and ground water in intermediate valleys and ground water on adjacent plains.
- Ground and surface water managed conjunctively in intermediate valley.
- Over-appropriated stream.
- Ground water levels generally falling both in valley and on adjacent plains.
- Much wetland and related habitat exists along rivers and adjacent to canals and irrigated areas.
- Instream flows enhanced over natural condition by irrigation in some stream reaches but are in stress in some reaches during some months as result of storage and stream diversions.
- Salinity levels high in downstream reaches during low flow periods.
- Some quality degradation in ground water.
- Some degradation in surface water quality.
- Demands for both agricultural and nonagricultural water is increasing.
- Flexibility of storage and management system is high.
- Opportunity for irrigation water conservation is high, resulting in reduced diversions, reduced return flows, reduced consumptive use by phreatophytes and reduced evaporation from seeped areas.

Selected objectives	*Prescription or alternative actions*
a. Improve water quality and increase benefits of current water supply for all uses.	1. Improve conveyance systems (canal and lateral lining, pipelines and regulating and measuring structures). 2. Improve onfarm surface systems (ditch lining, gated pipe, land leveling, measuring devices, best adapted method of irrigation). 3. Conversion to sprinkler systems. 4. Irrigation tailwater control and reuse. 5. Irrigation water management. 6. Reduce phreatophytes where appropriate. 7. Increase reservoir storage where appropriate.
b. Protect and enhance instream flow values.	*(Prescriptions of objective "a" also apply to "b")* 1. Manage reservoir releases to meet instream flow needs as well as for authorized purposes (may need legislative authority). 2. Construct facilities to manage return flows for instream flow needs. 3. Purchase water rights to be left instream or for release from reservoirs as appropriate. (Legislative action may be needed.) 4. Develop a conjunctive management plan of wetlands and streamflows to maximize social benefit from both.
c. Sustain use of ground-water aquifers, including quality control.	1. Expand technical and data collection capability of State water administering agency to facilitate better management of water rights and ground-water use. 2. Establish acceptable rates of ground-water withdrawal through data analysis and full public involvement in rate-setting process.

Selected objectives	*Prescription or alternative actions*
	3. Reduce or eliminate consumptive use by low priority uses. 4. Reduce seepage and other recharge of ground water where recharge water is of low quality.

Condition or Situation

Scenario II.

- Irrigation occurs primarily in lower valley.
- Water supplied from sources outside of basin.
- Ground-water mining occurring in some areas.
- Local surface water, imported water, and ground water conjunctively used.
- Fully appropriated stream.
- Little native vegetation in irrigated area.
- Wetland wildlife habitat management areas designated and use return-flow water.
- Current instream flow conditions greatly modified over natural conditions.
- Soil salinity levels high where drainage facilities are inadequate.
- Quality of inflow to estuary is an issue.
- Demand for water for agricultural and nonagricultural purposes increasing.
- Flexibility of storage and management system is high.
- Opportunity for irrigation water conservation is moderate as some systems are currently operated at relatively high efficiency.

Selected objectives	*Prescription or alternative actions*
a. Improve water quality in local areas as well as that flowing to estuaries.	1. Irrigation tailwater control and reuse. 2. Control over major drainage and freshwater releases at critical times. 3. Reduce return flows and over-leaching through irrigation water management.
b. Manage existing water supply to meet changing agricultural, municipal, and industrial needs.	1. Line and manage canals to reduce seepage and spills. 2. Reduce incidental uses and irrecoverable ground-water losses by better onfarm systems and water management (revise or change systems, measuring devices, automation, irrigation scheduling). 3. Leave "saved" water in reservoir for subsequent or additional use, or leave it in underground aquifer. 4. Provide additional storage to permit better management of water supply. 5. Expand facilities for recharge of aquifers.
c. Prolong life of ground-water aquifers, including quality control.	1. Enact State laws that provide for the protection and use of ground water as a continuing resource. 2. Provide for collection of data that will facilitate establishment and control of ground-water areas. 3. Provide for drainage facilities that will reduce contamination of ground water from seepage of saline or other low quality water. 4. Manage surface and ground-water supplies so that ground water is used primarily during times of drought and less during years of normal or high precipitation to allow ground-water levels to recover.

Methods need to be developed for coordinating water application for nonirrigation purposes, such as soil conditioning for traction and harvesting, climate control, and fertilizer application, with the irrigation water requirements of the crop.

Public and private research in the area of automation has led to the development of such equipment as center pivots, drip systems, and automatic gated pipe. Each of these systems has characteristics relating to labor use, water use, application rate, energy use, and cost which limit their adaptability to various irrigation situations. Research and education efforts which examine techniques and equipment with respect to their physical and economical adaptability to various irrigation situations could lead to better equipment, crop, and management technique selection for the irrigation situation.

Research also should be conducted to evaluate the energy conservation potential of any proposed water conservation measures. The long-term economic feasibility of some measures may depend on low-cost energy.

Ongoing research in salinity-resistant crops should be continued and expanded in areas which now require significant quantities of irrigation water to meet leaching requirements. Changes in crop selection or crop varieties could result in reduced water needs in the southwest and intermountain areas.

Some other research needs include (a) improved instrumentation for monitoring flows and ambient atmospheric and root zone conditions, (b) new ways of reducing evaporation losses, (c) tailwater elimination or reduction, or improvement of reuse practices, (d) improved control and water measurement devices for onfarm water distribution, (e) new plastics or synthetics as raw materials for improved, low-cost irrigation system components, (f) improved control of water intake rates of irrigated soils, (g) improved screening and diversion structure design to prevent loss of young fish, (h) relation of water conservation measures to meeting water quality goals, and (i) agricultural use of municipal and industrial effluents.

The benefits to be gained from achieving the research objectives outlined above will include (a) increased agricultural production, (b) stabilized food production and farm income, (c) savings in water, fertilizers, and energy, (d) improved timeliness of conducting farming operations, and (e) conserved resources and environmental protection.

Technical Assistance and Education

There is always a gap between the state-of-the-art as determined by research and actual practice. Sound education and technical assistance programs can reduce this gap in irrigation water use and management. Demonstration projects are needed to translate research findings to field situations. Irrigators cannot afford to undertake costly improvements unless their success has been demonstrated. State water agencies together with universities and extension services are well equipped to provide leadership for the demonstration of all types of water conservation measures. Priorities in each State need to be set on those measures most suited to improve water use in irrigated agriculture and education programs should be developed accordingly. Special interagency programs, as on the Wellton-Mohawk Irrigation and Drainage District, can be useful in providing technical assistance for and demonstrating water conservation.

Adoption of more advanced technology in water use and management creates a problem for many irrigators and irrigation districts. For example, because of the lack of technical assistance in the past, some sprinkler irrigation systems have been installed in such a way that the potential for highly efficient operation has not been achieved. Thus, the water conservation objective has not been reached. Timely assistance from Federal and State agencies and private industry is needed to prevent incorrect or inadequate installation of the more complex measures. Technical assistance programs should be geared to the priority objectives and measures determined with a State, utilizing the private institutions to the extent possible.

Incentives

One of the most complex problems in this country is to determine what kinds of incentives, if any, are necessary to reach national goals. Under the current water policy, water conservation is a national priority and certain actions are proposed in accordance with this policy. Local water officials have stated that much is being accomplished under ongoing programs, and the trend analysis shown in table 14 indicates what improvements in efficiencies can be expected. Because of the extensive offsite and downstream benefits from improved irrigation practices as compared with onsite benefits, some increased public financial assistance in the installation of the more costly measures will be required if any significant shift toward the national water conservation objective is to be achieved.

However, this increased assistance should be directed initially to those areas with water shortages, ground-water management problems, critical instream flow conditions or other environmental problems. An analysis of the effectiveness of such programs should be made. Increased assistance for water conservation practices primarily for food production and agricultural economic stability also is important over the long run and should be considered in establishing cost-sharing criteria for water conservation measures.

The investment of $14.6 billion to implement the measures necessary to bring irrigation water use and management to the level of today's state-of-the-art may not be realistic because of environmental, economic, and social constraints. Many areas appear to have substantial justification for implementing water conservation measures over the next 10 to 30 years. The Nation should be prepared to invest, in addition to ongoing programs, up to $5 billion over the next three decades for measures to accomplish irrigation water conservation objectives. Current Federal programs generally provide technical assistance, interest-free or low-interest loans, or direct cost sharing for such purposes. The Federal/State/local cost-sharing aspects of those programs are being evaluated as a part of implementing the President's water policy, and it is assumed that the national, regional, and water user benefits that derive from increased agricultural water use efficiencies and that are described in this report will be given due consideration.

Other Institutional Measures

In the States where the Doctrine of Prior Appropriation is used, it is felt that for the most part sufficient flexibility exists under State law to manage the water resources efficiently. To improve the administration of water rights, more personnel would be needed, with more accurate data on water availability and water use. Waste and inappropriate use of water can be detected and pursued effectively only with reliable data and sufficient manpower. Collection of data on ground-water aquifers, including recharge rates and potentials, should be given priority. With better data on ground water, more effective use can be made of both ground and surface supplies in normal years and during periods of drought. In some States, revision of the water code is needed to provide protection for instream flow values.

In some instances water pricing has been used to reduce water use. Water pricing should be considered by all supplying organizations as a means to conserve water. Several Federal agencies (principally the Bureau of Reclamation), some State agencies, and many local organizations have an opportunity to reconsider water pricing policies. Rate structures can be adjusted to lower base rates but make those increments of water use in excess of needs for efficient irrigation more costly. In this way, water users must consider whether additional increments of water are cost effective. The total funds assessed in the district need be no more than is required to meet the obligations of the district. The marginal cost (price) of additional units of water could be set at the opportunity cost of water in the local market area, or could be set at a level that would meet conservation objectives. Graduated water pricing would be applied primarily to surface supplies. Energy costs alone tend to accomplish the same purpose where water from deep wells is pumped for irrigation.

This principle has been implemented in some irrigation districts as follows: When water is delivered, the irrigator is assessed on a quantity of water basis; the district declares a base water supply which is available on a flat rate, taking into consideration variations in soils, crops, and management practices; and the unit water rate increases substantially for deliveries in excess of the base quantity. This encourages more efficient use of water, improved facilities, and good management practices.

Where water is supplied under a contract with governmental water developers, the dollar rate is set along with an allocated quantity of water. This allocation is the amount needed for supplementing other available supplies. In these cases, the quantity allocated should not allow for inefficient use of the supplemental supply. The dollar rate for water may be set for a predetermined period of time. The current policy (since 1976) is for the Bureau of Reclamation to adjust water prices every 5 years. Contracts entered into prior to that time do not have provision for adjusting water price.

Federal-State Coordination

Most Federal programs which provide assistance in irrigated areas do not have water conservation as a primary objective. As a result, coordination among Federal programs and between Federal and State agencies in this regard has not been fully achieved. The primary means of bringing this about is through the adoption of explicit national water conservation objectives and by aligning Federal and State programs to these objectives. Annual budget justification statements should specify funds and manpower that will be directed to the water conservation objective.

Better coordination is needed between the water resource entities and the environmental groups. The implementation of some measures may be restricted or postponed because of environmental conflicts. Loss of wildlife habitat caused by the reduction of seepage is an example. The cost of mitigation or compensation may cause the cost of some measures to outbalance the projected benefits. Better coordination among interested parties and better management of project facilities to protect remaining habitat could result in reducing these costs.

Federal Role

The Federal role in irrigation water conservation as set forth in this report is to provide assistance to encourage and support *Cooperative Water Conservation Programs* developed in the States. It is clear from a review of chapter 3 that there are Federal programs available to assist in most phases of any comprehensive conservation program. The President in his water policy statements has pledged support for grant assistance to States for water conservation technical assistance and has asked a number of Federal agencies also to provide increased technical assistance for water conservation.

This report recommends that each Federal agency set forth explicitly in its annual budget request specific dollar and manpower amounts to meet stated water conservation objectives. These should not be developed independently, but should result from the agency's participation in the State *Cooperative Water Conservation Programs.* Also, the sum of agency requests should be analyzed against the total workload as set forth in this or other study reports. To accomplish this, those principal Federal agencies involved — Department of the Interior, Department of Agriculture, and the Environmental Protection Agency — should enter into a Memorandum of Understanding to develop annually a coordinated plan and Federal budget for irrigation water conservation. As a minimum, such an annual plan should address the following areas: Technical assistance, cost-sharing and other incentives; research, education, and demonstration; and coordination with other Federal and State programs.

A monitoring program should be established to measure progress in meeting national water conservation objectives. Progress should be measured in terms of improved water management, improved off-farm and onfarm systems, and the resulting reductions in water use, increases in productivity, improvements in water quality, improvements in instream flow conditions, and improvements in ground-water conditions.

Glossary

A number of technical irrigation terms have a variety of meanings or interpretations, even among irrigation experts. The following definitions will be used consistently throughout this report. For an understanding of additional terms related to hydrology, refer to the section describing river basin hydrology in chapter 1.

Center-pivot sprinkler: A mechanized agricultural irrigation system consisting of a pipeline supported above the crop, on mobile towers. Water is applied from sprinkler or spray heads on the pipeline. The pipeline is fixed at one end, the pivot, where it is connected to the water supply. Sophisticated controls on the towers regulate their motion to move the pipeline slowly in an arc about the pivot. Typical center-pivot sprinklers are one-fourth mile long and irrigate 135-acre circular fields.

Characterization areas: As used in this report, they are large areas (regions) with relative homogeneity with respect to factors affecting irrigation development.

Conveyance system (delivery system): A system of canals, pipelines, conduits, control structures, turnouts, and other devices used to deliver irrigation water from the water supply to the farm.

Crop consumptive use (crop consumptive requirement): The evapotranspiration of a crop (water stored in root zone and used by crops) during its period of growth. It does not include water for leaching, germination, frost protection, or other cultural practices.

Drip (trickle) irrigation: An irrigation method in which water is delivered to or near each plant in small-diameter plastic tubing. The water is then discharged at a rate less than the soil infiltration capacity through pores, perforations, or small emitters on the tubing. The tubing may be laid on the soil surface, be shallowly buried, or be supported above the surface (as on grape trellises).

Efficiency:

> *Off-farm conveyance efficiency:* The volume of water delivered to the farm, expressed as a ratio or percent of the volume of water diverted (gross diversion) from a stream or other water supply.
>
> *Onfarm efficiency:* The volume of water stored in the soil root zone and used by the crop, expressed as a ratio or percent of the volume of water delivered to the farm. Onfarm efficiency characterizes both the onfarm distribution system and the field application systems.

Estuarine inflows: The freshwater flow regime necessary to provide for nutrient input, sediment movement, circulation, and maintenance of brackish conditions for estuarine organisms.

Evapotranspiration: It includes evaporation of water by all means, including transpiration by plants, evaporation of water intercepted by plant surfaces, and evaporation from soil, ice, and snow surfaces.

Gross diversion (withdrawal): The total quantity of water diverted from a stream, lake, or reservoir, or removed from the ground, for the purpose of irrigation. This amount can be greater than the water supply in a basin because of return flows and subsequent rediversion downstream.

Ground-water mining (overdraft): Pumping of ground water for irrigation or other uses, at rates faster than the rate at which the gound water is being recharged.

Irrecoverable water loss (incidental loss or use): That part of water diverted and lost that becomes unavailable for reuse after it is diverted from a stream or other water supply for purposes of irrigation. Irrecoverable loss includes evaporation from canals and inline reservoirs, evaporation from wetlands, phreatophyte and hydrophyte transpiration and that portion of groundwater recharge that is not economically recoverable in a reasonable number of years. Evaporation from streams and water supply or storage reservoirs is not included. Does not include return flows to estuaries or direct to oceans.

Irrigation situations (settings): As used in this report, they are four distinctly different situations under which irrigation is practiced in the characterization areas.

Instream flow needs: The flow regime necessary to provide for the combined instream uses for fish, wildlife, recreation, navigation, hydroproduction, waste assimilation, and downstream conveyance.

Leaching requirement: The water that must pass through the root zone in cropped areas in order to prevent soil salinity from reaching a level hazardous to crops being grown.

Mitigation: Partial replacement of resource values (usually fish and wildlife) lost or damaged as a result of a project undertaken for another purpose.

Natural flow depletion ratio: The ratio of rate of consumptive use of water in a hydrologic unit to the average annual rate of streamflow in the basin prior to development of the water resource.

Net depletion: Includes all crop consumptive uses and irrecoverable water losses. Does not include return flows to estuaries or direct to oceans.

Normal year: A year in which the amount of precipitation is equaled or exceeded 5 years in 10 (approximately equal to the average annual rainfall).

Onfarm system: The method used to distribute and apply the water to fields. Included are gravity or surface systems and pressurized systems such as sprinklers or drip. Tailwater disposal or recovery systems are included.

Return flow: That portion of the water diverted for irrigation that returns to ground water or stream system for potential rediversion or instream uses.

Saline: The condition of containing dissolved or soluble salts. Saline soils are those whose productivity is impaired by high soluble salt content. Saline water is that which would impair production if used to irrigate sensitive crops without adequate leaching to prevent soil salinization.

Surface irrigation: Any irrigation method where a stream(s) of water is applied to the soil surface at one boundary of a field and allowed to infiltrate as it flows across or ponds on the field surface. Furrow, corrugation, level basin, graded border, contour or border ditch, and wild flooding are all methods of surface irrigation.

Transpiration: The process by which water in plants is transferred into water vapor in the atmosphere.

Water delivery methods:

Rotation: Supplying water on a preset schedule basis from a distribution system to individual farms for a fixed period of time.

Demand: Supplying water at a rate and duration of flow to satisfy requests any time during the growing season with no advance notice.

Modified demand: Supplying water on advance notice at requested times, rates, and durations, or at rates and times commensurate with other irrigators' requirements along the distribution system.

Continuous flow: The continuous and constant discharge of a farmer's share to the farm.

Water loss: That portion of diversion that is not consumptively used by crops on a farm or project. Losses occur as a result of seepage, deep percolation, unrecovered surface runoff, evaporation from canals or from wetlands, and phreatophyte use. A portion of such losses returns to water bodies in the river basin and becomes available to other uses.

Water saved (salvaged): That water gained in a river basin through reduction of incidental uses and irrecoverable ground water.

Withdrawal: (used synonymously with diversion in this report) Water taken from surface or ground-water sources, to be used for irrigation.

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